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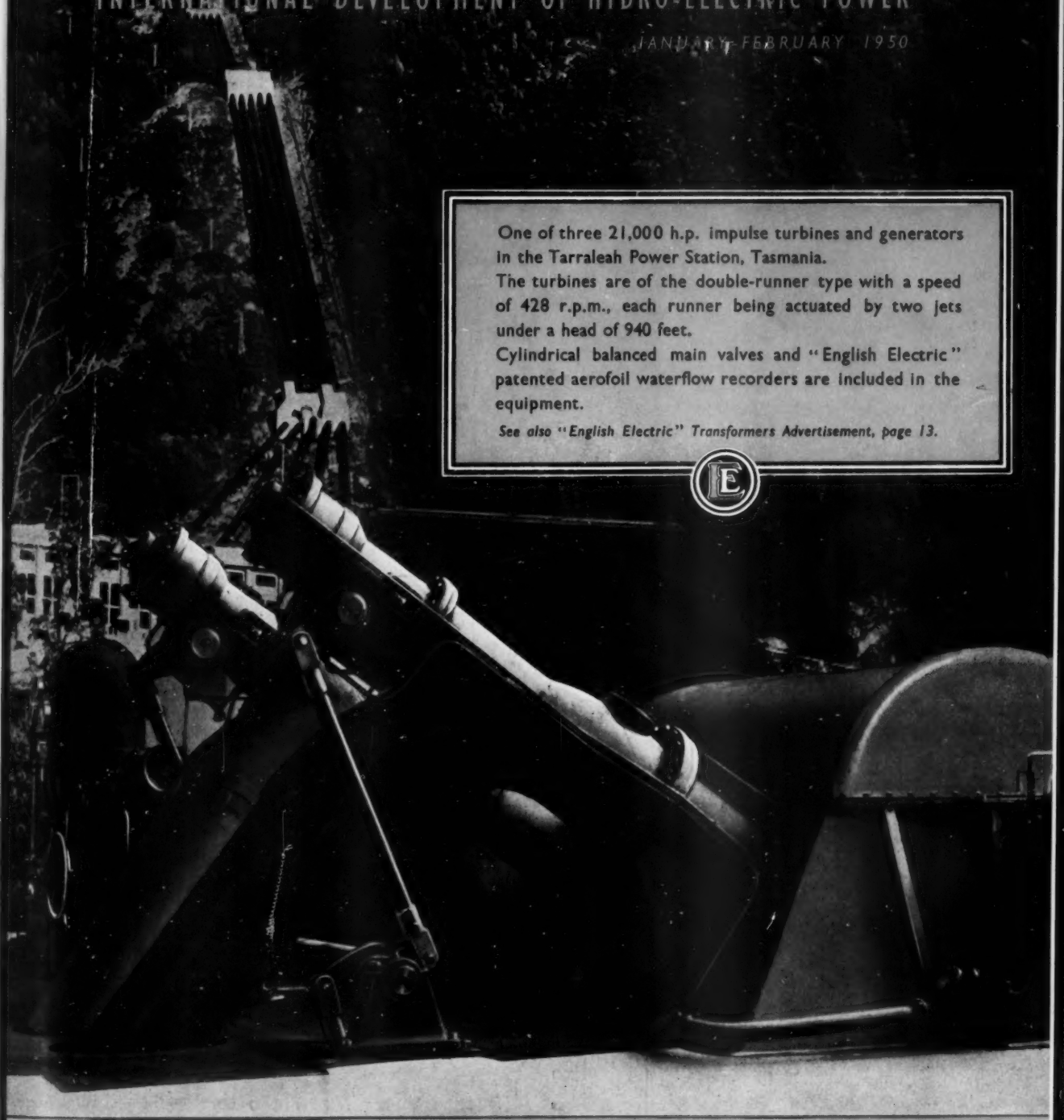
INTERNATIONAL DEVELOPMENT OF HYDRO-ELECTRIC POWER

JANUARY-FEBRUARY 1950



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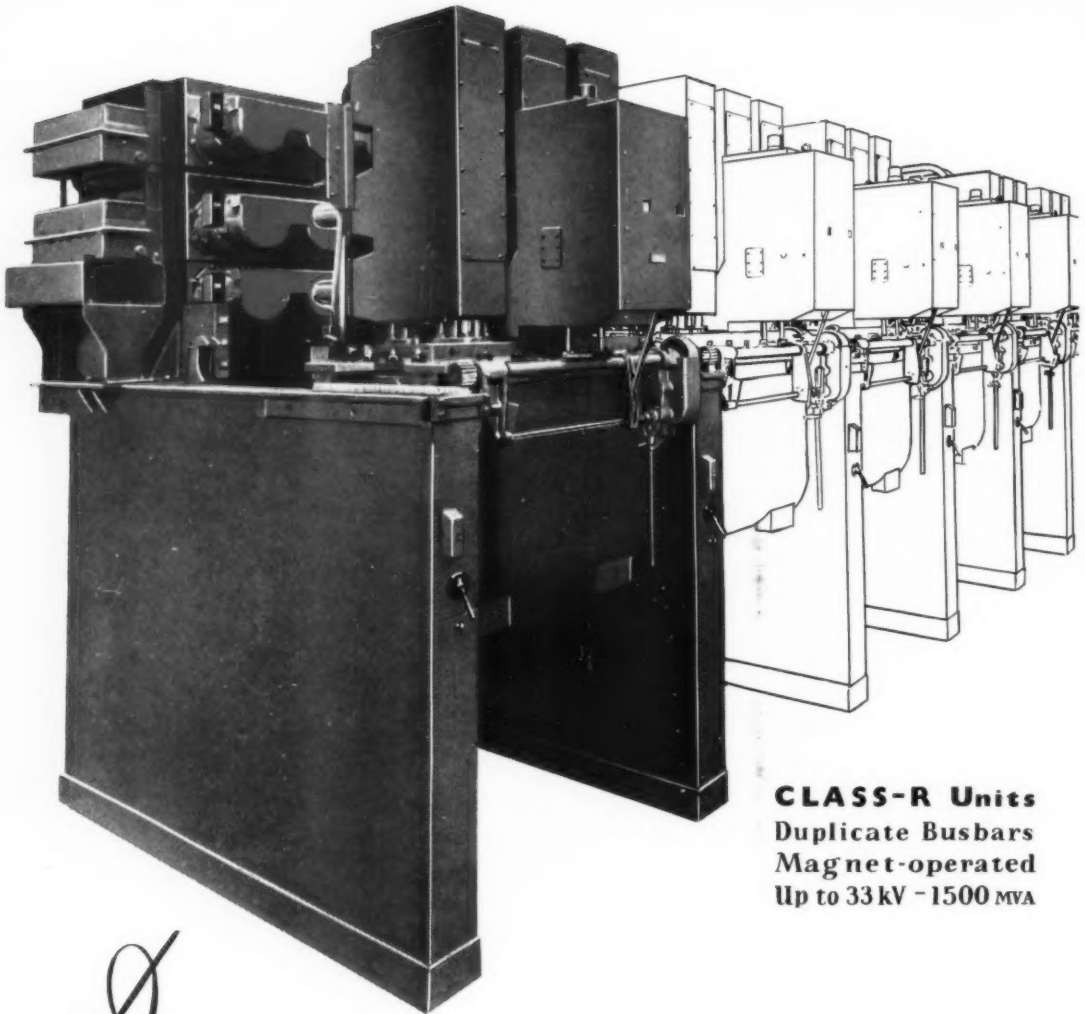

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CONTENTS FOR JANUARY—FEBRUARY 1950

Leading Article: Scotland - - - - - - - 1

Editorial Notes - - - - - - - - - 2

Missouri River Basin - - - - - - - - 5
by Richard G. Baumhoff

French Tidal Projects - - - - - - - - 14
by F. J. de Vos

The Scottish Scheme - - - - - - - - 20

The Design of Transmission Systems - - - - - 32
by W. A. Morgan

The Ybbs-Persenbeug Scheme - - - - - - 37
a comment by Dr. Chas. Jaeger

Hydro-Electric Expansion in Brazil - - - - - - 39

Book Reviews - - - - - - - - - 41

Spanish Water Power Developments - - - - - 44
by Rolt Hammond

Contractors' Notes - - - - - - - - - 48

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Scotland

BEFORE a recent visit to Clunie to inspect the new hydro-electric station our travels in the Highlands had been restricted to the pages of Scott, Stevenson and the learned Dr. Johnson. Perhaps it was the last named who left the deepest impression with us for at the time of his journey, in 1775, there was much distress among the inhabitants. Poverty was widespread and emigration the order of the day.

In spite of the many witty sallies Dr. Johnson launched at things Scottish he was deeply moved by what he saw and his criticism of the neglect to which the population was subjected was an indictment that was not without good effects. Since those days, of course, much has been done to rehabilitate the Highlands; but the final answer—or the beginning of it—surely is in the hands of the North of Scotland Hydro-Electric Board. It is easy to believe that had the good Dr. Johnson been alive to-day he would have been the first to applaud their work and achievements.

These reflections have their origins, possibly, in his classic remark, "Sir, the noblest prospect which a Scotsman ever sees is the high road that leads him to England"; for our part, however, we have no wish to see any nobler prospect than the opening gorges of the Highlands where their first impress of grandeur is impacted on the mind, and we hope all good Scotsmen will find in this opinion a small requital for an ancient offence.

Since its inception in 1943 the Board has published sixteen major constructional schemes, embracing nineteen projects for the generation of electricity. These schemes will involve the construction of 29 hydro-electric stations containing 56 turbine-driven alternator sets with an aggregate capacity of 630,000 kW and an annual output amounting to about 1,700 million kWh—or some 42 per cent. of the annual consumption of electricity for the whole of Scotland. The potential resources are very much higher than this, however, and as a result of a survey published in 1944 the Board placed the ultimate output figure at 6,274 million kWh. A more complete survey would no doubt reveal additional resources, for the operational area covered by the Board—if transmission and distribution be included—is a very extensive one, covering about 21,780 square miles or about 74 per cent. of the total area of Scotland.

A mountainous tract so widespread affords a great variety of conditions, which in turn make their particular demands on generating plant. The largest turbine installed is of 53,000 h.p. and is coupled to an alternator of 40,000 kW capacity; but other plants, serving isolated districts, may be as small as 200 kW capacity. Operating heads range from 1,362 feet at Lawers down to 16 feet at Morar. As for turbines the Kaplan, Pelton, and, of course, the ubiquitous Francis, are all represented; the largest Kaplan being coupled to a 13,000 kW alternator and the largest Pelton producing 30,000 kW.

Measured by some of the sets installed in the vastly more favourable conditions obtaining in other countries these outputs might seem small; but they are by no means insignificant to Great Britain. For example, when fully developed it is estimated that the output from the Board's hydro-electric stations will replace the consumption of four million tons of coal a year, representing the work of 14,800 miners at their present rate of production. Alternatively, if exported, say to Denmark, this coal would be equivalent to 30,000 tons of butter for the national larder.

The place occupied by the new Clunie power station in this development is considered elsewhere in the current issue. Though a notable engineering achievement, Clunie does not offer any novel departure from orthodox lines and from the technical point of view interest tends to concentrate on the two drum gates which have been erected to maintain the impounded waters at a constant level. We believe this to be the first occasion in which drum gates of this type have

been used on this side of the Atlantic and they certainly solve, in a very ingenious way, a very real problem.

The Clunie station is scheduled to come into operation in the early spring, possibly before our next issue goes to press, and the next project to reach maturity will be the Loch Sloy scheme, in the Loch Lomond area, some 30 miles from Glasgow. Here four 32,000 kW vertical-shaft Francis turbines will be installed, together with a 450 kW Pelton-driven auxiliary set, the whole operating on a head of 910 ft. Unusual interest attaches to this scheme as one of its main objectives is to meet the sharp peaks which occur in the electrical load in Central Scotland in the winter season. The rapidity with which a hydro-electric alternator can be put on load compared with a steam plant, combined with the fact that the rainfall in this region is very much heavier in winter than in summer, provide a set of circumstances particularly favourable to this plan, for the large electrical network with which Sloy is to be connected is preponderantly supplied from steam stations.

Major Schemes in India

WE ARE INDEBTED to Mr. K. P. P. Menon, utilisation member of the Government of India's Central Electricity Commission, for the following comments on the article "India's Major Schemes" which appeared in the September-October issue of *WATER POWER*:—

A recent estimate now puts the present installed capacity figure at two million kW. In regard to the future installations amounting to 15 million kW it will not be difficult to imagine what this means in terms of men, materials and finance. Nor should we forget that the installation of 15 million kW of power implies the establishment of industries to consume the electricity that will be generated. The extent of capital required for such large scale industrialization, having regard to the present state of India's finances means that this programme will have to be spread over a number of years.

India's plans for development are at present more modest, because of economic stringency and the shortage of trained technical staff. In the next five-year period the aggregate additional hydro generating capacity is expected to be of the order of half a million kW and in the subsequent quinquennial period about .65 million kW.

Coming to the various projects, the Damodar Valley development scheme has been considerably modified since its original conception and it is expected that the total cost of the scheme will substantially exceed the £41 million estimate which was based on preliminary investigations. The power plant installations under the project will include 150,000 kW (200,000 kW ultimate) of thermal plant, and over 200,000 kW of hydro plant. The plant for the thermal power station has been ordered, and in the near future orders will be placed for a small hydro electric plant of 4,000 kW capacity. Work on the design of the dams and other works are in different stages of progress. The installations of hydro power plant will be spread over a period of years, depending on the growth of load in the area.

Under the Bhakra Scheme the irrigation works will be proceeded with as quickly as possible. The installation of power plant will, however, be postponed until the output from the Nangal project (capacity now under installation 48,000 kW, ultimate 72,000 kw in each of the two stations) is absorbed. Ultimately, when the electrical works under Bhakra are undertaken, the total installed capacity may be about 540,000 kW.

The Kosi scheme is still under investigation. Here also, the irrigation and flood control will be given higher priority, the power installations following later, depending on the load demand.

The Jog scheme in Mysore is being developed in two parts: the first stage with four 12,000 kW sets, and the second with four 18,000 kW sets. The first stage has been completed and the second stage is in progress.

The statement (on page 212) that "the first generating unit at Mysore has been operating for about 18 months at 1.260 kW" is incorrect, says Mr. Menon. The reference probably referred to the first 12,000 kW set in Jog which was commissioned late in 1947. The Jog scheme is primarily meant for power development; there is very little direct irrigation from this project.

In regard to the development of the Mahanadi Valley, the Hirakud dam and the associated works are being taken up now. The cost of this scheme, which will ultimately generate 321,000 kW, is expected to be about Rs.47.5 crores or £35.5 million. No estimates have yet been given for the Naraj and Tikarpara Schemes.

Electricity Production Scheme

THE Central Electricity Commission of the Government of India had its report for the year 1948 ready by the end of October. This is a commendable feat as the partition of India is still relatively recent and the Governmental machinery available for compiling the vast number of statistics required for the presentation of a complete report, dealing with no less than 363 generating stations, must have been highly efficient.

Dealing only with Public Supply Undertakings the report shows that 1.4 million kW of generating capacity produced 4,575 million units during the year 1948, an increase of about 12 per cent. over the previous year. The 33 water power plants covered in the report contributed nearly 52 per cent. of the total energy generated.

Power Supply in Pakistan

THE inauguration of a new transmission line from Peshawar to Kohat in the North West Frontier Province is a step towards the reinforcement of the power supplies in that part of Pakistan. The Malakand station from whence the power is obtained is one of the principal stations in Pakistan, and work is proceeding on extending the power plant by the addition of four generating sets of 5,000 kW capacity which are on order from Westinghouse Electric and Manufacturing Company of U.S.A. The present size of the station is 10,000 kW and it is hoped that the capacity of the station will be doubled this year.

Joint Engineering Conference

THE councils of the Institutions of Civil, Mechanical, and Electrical Engineers have decided to hold a joint engineering conference in London in June next year, to coincide with the Festival of Britain.

The theme of the conference will be place on record the achievements of British engineers and will afford an opportunity for the engineers of the world to discuss the future trends of developing the great sources of power in nature for the use and convenience of man. The conference will also underline the interdependence of all branches of engineering, for none of the great developments in the last 100 years would have been possible without the constant and ever-growing cooperation of the members of the three major engineering institutions in Great Britain.

Mindful of the importance of maintaining the high standard and technical efficiency of British engineers in the future, the conference will also discuss the development of the system of education of engineers in Great Britain which, by the achievement of British engineers, has shown itself to be pre-eminently suited to the conditions in this country. The detailed arrangements of the conference are now being prepared.

Snowy Mountains Hydro-Electric

MR. EDWARD F. ROWNTREE, B.Sc., B.Mech.E., has been appointed chief investigating and designing engineer to the Snowy Mountains Hydro-Electric Authority in Australia. He was formerly on the engineering staff of the Comdmonwealth Department of Works and Housing as engineer-in-charge of major investigations.

The Snowy Mountains Hydro-Electric Authority has been formed by the Commonwealth Government to undertake the design and construction of Australia's largest power project involving 16 hydro-electric stations with a total capacity of 2,620,000 kW. The cost of the whole scheme will exceed £200 million. At the present time staff is being recruited, aerial maps are being prepared and designs are being worked out. Mr. W. H. Hudson, a graduate of the London University, is chairman of the Authority. Mr. R. F. Archer is the secretary at 85 O'Riodan Street, Alexandria, Sydney.

From 1949 to 1957 the capacity of Australia's power plants (steam, oil and hydro-electric) will be increased by 2,360,000 kW. This amount is more than double the 1949 installed capacity. The figures of additional capacity do not include the huge Snowy Mountains scheme because of lack of information on completion of any of the hydro-electric plants embraced.

Projects listed for completion by 1957 include 57 power stations with an estimated total expenditure of £194,000,000.

Developments in New Zealand

STATE HYDRO-ELECTRIC DEPARTMENT of New Zealand has called tenders for plant for a 100,000 kW power station to be built at Whakamaru, North Island. This station will be on the Waikato River above Maratai. A concrete gravity dam 180 ft. high and 900 ft. long, flanked by earth dams, will be built. Four generating units, each of 25,000 kW will be installed in the power station which will be set across the river immediately below the dam. The station is expected to be in operation by 1955.

Tenders have also been invited for the supply of plant for the Roxburgh scheme in South Island. This project will have a total generating capacity of 320,000 kW; the initial installation will be 160,000 kW.

Expenditure on hydro-electric schemes in New Zealand will soon reach £7,000,000 a year. With the works projected at the moment £53,000,000 will be spent over the next seven years. Mr. A. E. Davenport is general manager of the State Hydro-Elctric Department. His address is:—P.O. Box 25, Government Buildings, Wellington, New Zealand.

Southern Rhodesia Project

IT is semi-officially stated that a start on the great Hunyani Poort Dam near Salisbury, Southern Rhodesia, will be made early in the new year. It has been decided that the dam shall be built of earth and rockfill, and the cost will be in the region of £854,000. Its capacity will be about 55,000 million gallons. An irrigation department official said recently that about 30 firms in various parts of the world had shown an interest in the project, and that it was expected many would submit tenders. It is hoped to have the dam ready for use by the end of 1951.

A Power Plant for Israel

JOHN S. COTTON, consulting engineer of San Anselmo, California, has been engaged by the State of Israel to prepare a master plan and designs for irrigation and power development in Israel. This involves bringing the waters of the Jordan river from the northern boundary to the southern end of the country for irrigation, and conducting Mediterranean sea water to the Dead sea, which is about 400 metres lower than the Mediterannean, for the generation of power. The sea water, after generating power, will be evaporated.

Rio Lindo, Honduras, Surveyed

PRELIMINARY surveys have been made by the United States firm of Sanderson and Porter, and by engineers of the Tela Railroad Company, of the possibility of a hydro-electric development on the Rio Lindo.

The Rio Lindo is fed by a subterranean stream from the nearby Lake Jojoa, and there have been reports that this lake is showing signs of drying up. So far the results of the survey have not come to hand.

Springtime photograph of the Green Mountain dam spillway; the last of the melting snow lingers in the channel

Missouri River Basin

By Mr. RICHARD G. BAUMHOFF. A comprehensive article on the developments in hand and being planned to use the resources of this mighty river.

Dans cet étude d'ensemble de la mise en valeur du bassin du Missouri, l'auteur examine les circonstances politiques qui ont eu une influence importante sur l'établissement et sur le développement des projets hydro-électriques. Il existe un plan de construction, sur le cours supérieur du Missouri lui-même, de sept barrages, chacun alimentant ses propres stations génératrices; plusieurs de ces ensembles sont en eux-mêmes d'immenses entreprises. L'auteur donne les chiffres estimés de capacité hydro-électrique. L'United States Federal Power Commission a entrepris une nouvelle étude des ressources de houille blanche et l'on s'attend à la publication prochaine de son rapport.

Un articulo muy comprensivo versando sobre el desarrollo del cauce del Río Missouri. El autor discute los aspectos políticos, los cuales pueden influenciar en proporciones de importancia el establecimiento de proyectos hidro-eléctricos y de otras fases de progreso. Existe un plan para la construcción de siete presas a través del Río Missouri propiamente dicho, cada una de ellas con estaciones generadoras de fuerza motriz y todas ellas dispuestas en la sección de aguas arriba; varias de estas obras constituyen enormes empresas individuales y se facilitan cifras calculadas relativas a la capacidad hidro-eléctrica instalada. La Comisión Federal de Energía de los Estados Unidos de la América del Norte ha iniciado un nuevo estudio de los recursos generadores hidro-eléctricos y se espera que muy pronto presentará el informe correspondiente.

EXCEPT for the south western deserts and some limited areas of the deep South, the Missouri River basin, as a whole, has been the most neglected region of the United States. Its population is relatively sparse, its economy is dominated by absentee industrialists and financiers, and its human and physical development is backward in many important respects. Fortunately, a new day is dawning for the basin. Hydro-electric power will shine brightly in that new day.

The Missouri, one of the world's longest and mightiest streams, has been an unruly demon from time immemorial. In the lower and richer part of the valley it has had countless disastrous floods, while the upper end of the basin is semi-arid. If men no longer protect their valuable and life-giving water rights in the parched upper end with shotgun and pistol, they still fight for them in the highest courts and in the state legislatures and the national Congress.

The greater part of the Missouri basin consists of the Great Plains of the Northwest and other rolling prairies. There, Indians and bison once roamed and lush native grasses held the soil. The white man and his plough changed all that, and now the fertile top soil is gone or almost gone over large stretches of the land.

Like a huge funnel, the Missouri basin is stretched across the United States, its point flowing into the Mississippi at St. Louis, in the State of Missouri; while its far-flung upper reaches, fed by many big and little tributaries, extend to the Continental Divide in the Rocky Mountains. This basin covers one-sixth of the nation but contains only about one-fifteenth of the population. It measures 529,000 square miles but has only perhaps ten million inhabitants, most of whom are in the fertile and industrialized eastern end. While it is six times bigger in area than the United Kingdom, its population is only about one-fifth of the latter's.

Here, then, is a region offering boundless possibilities for development, of important significance internationally as well as nationally. It is a last frontier of a nation which was still expanding westward half a century ago. It has great potentialities for agricultural, mineral and industrial development. Serious thought, both unofficial and official, has been given to the desirability of establishing key industries in this region, for the maximum protection in event of war. At present beef, mutton and wheat are the principal products.

Outstanding among the needs of the Missouri basin is the provision of more electric power—hydro-electric power, to be exact. Steps are under way already to provide this, and much construction is going on. Plans call for installed generating capacities of the order of millions of kilowatts with an annual output in terms of thousands of millions of kilowatt hours. The realization is just dawning that big steam plants will be needed also in order to assure a firm, year-round supply of electric power.

The hydro-electric phase is just one of a variety of undertakings contemplated for the control and development of the huge water, land and mineral resources of the basin. In fact, it has been treated so far as more or less an incidental phase—economically important to the success of the whole project, and desirable for the region, but a very touchy subject and a field where the legal authority to proceed is somewhat shadowy and incidental to other authorized functions.

The serious movement to improve the Missouri basin got under way a few years before World War II. People in the lower end wanted to get rid of the floods which plagued them; those in the upper end wanted more water for irrigation and for their cities; a small but politically powerful group favouring the barge operators sought improved navigation channels in the lower Missouri. The Army's Corps of Engineers dealt with flood control and navigation, the Bureau of Reclamation, an agency of the separate federal Department of the Interior, handled irrigation and land reclamation.

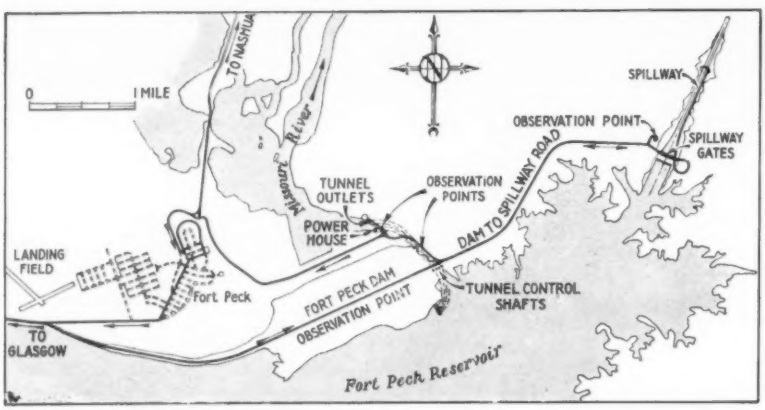


Fig. 1 (above): Aerial panorama showing the curving line of Fort Peck's 4 mile dam and dyke extension, with an expanse of placid water in the foreground. To the left is the Government town of Fort Peck and in the centre the powerhouse with the surge tank " tower "

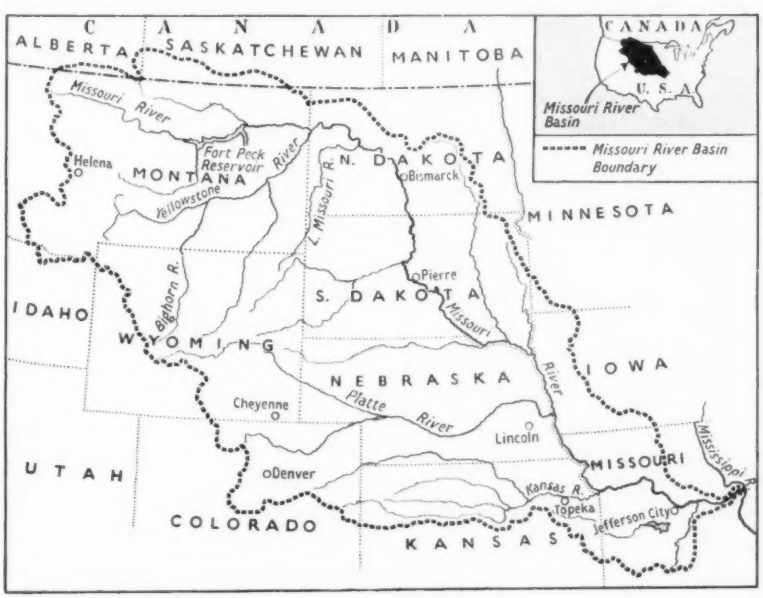
Fig. 2 (left): Sketch map showing layout of the Fort Peck scheme

Mr. W. G. Sloan, then an engineer for the Bureau of Reclamation, drew up one plan, emphasizing irrigation. Hastily, with the war already started, the Army's General Lewis A. Pick worked up a rival plan. Governors of some of the ten States which are partly or wholly within the Missouri basin became alarmed over the conflict of plans. In this atmosphere the movement for a federally created Missouri Valley Authority was born and grew lively. " MVA," as that proposal has become widely known, would be the administrative counterpart but far larger follower of TVA, the Tennessee Valley Authority.

MVA, supported by various liberal elements, has been bitterly attacked as " socialistic," " New Deal " and even " red," but just as stoutly defended by its adherents as a sound, sensible democratic instrument. Many of the early criticisms of TVA have been destroyed by practical experience. It took the late Senator George W. Norris, independent Republican of Nebraska, twelve years to obtain TVA, with the

Fig. 3 (above): Fort Peck tail race where water enters the river on the downstream side of dam. Surge tank "tower" in centre with transformer bank and switchyard on right

Fig. 4 (below): Map of catchment area of the Missouri River Basin

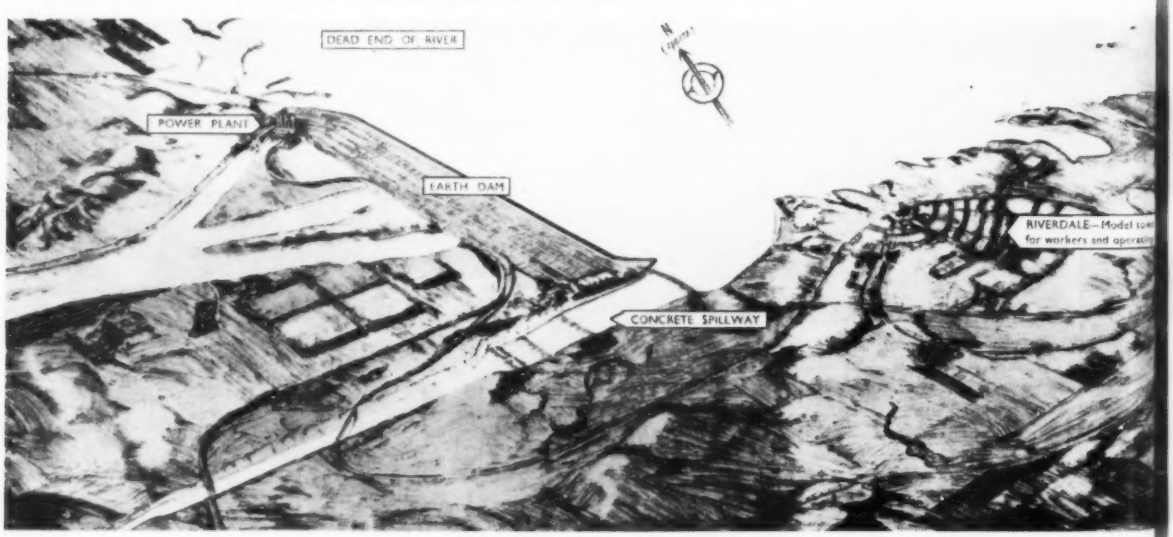


help of Franklin D. Roosevelt. Senator James E. Murray, wealthy Montana Democrat and liberal, aided lately by Senator Hubert H. Humphrey, Minnesota Democrat, and Senator Guy M. Gillette, Iowa Democrat is continuing the fight for MVA.

All this background of political ideology plays a definite part in the hydro-electric development of the Missouri basin as well as the other phases of development. The governors' alarms resulted in a reconciliation of differences and the official adoption of the combined Pick-Sloan plan, which Congress made law in the Flood Control Acts of 1944. In the following year the voluntary or extra-legal body known as the Missouri Basin Interagency Committee was formed. General Pick, who later built the famed Ledo Road in the China-Burma-India theatre of war,

Fig. 5: A fine view of the Green Mountain dam showing the beautiful surrounding scenery. The picture shows the height of the massive earth dam with the reservoir beyond and the powerhouse and transformer station in the foreground

Fig. 6 (below): Bird's eye view sketch map of the Garrison dam and reservoir on Missouri River. The construction of this project is well under way



and who is now the Army's Chief of Engineers, was its first chairman. Mr. Sloan, now a general representative of the Department of Interior, succeeded to the chairmanship.

The Pick-Sloan plan has been translated to all intents and purposes into the Interagency plan, a far bigger and more costly project, taking into account some plans of the State governments as well as the big jobs of the Federal Government. It embraces some individual pre-Pick-Sloan features, such as the great Fort Peck Dam in the upper Missouri river and an amazing diversion of water from the Colorado river to the Missouri basin under the high Rockies in the State of Colorado, now approaching completion.

The Interagency committee, which has no actual authority but has proved to be an excellent common meeting ground and public sounding board, assembles at regular intervals in the various States of the basin. It comprises one representative each from five major Federal departments and five governors representing the powerful unofficial organization of the governors of all the Missouri basin States. The committee claims, with some good reason, to be the coordinator of the plans; but it has had some setbacks too. Each of the Federal agencies and each of the States has its own rights, powers, duties, limitations and responsibilities under the law—and each has its own interests and human fallibilities.

Nevertheless this system of procedure has attracted strong support in the basin. There are many interests which like it and fear what they consider the authoritarian idea of MVA, which would be a single, unified agency, located within the basin and given broad responsibility. Whether the MVA supporters like it or not, Interagency is making progress and a great leaven is working in the Missouri basin.

Interagency's plan contemplates a total estimated eventual expenditure for construction of $8,500 million, partly by the Federal and State governments and partly by private owners of property. Funds actually expended up to June 30, 1949, exceeded $741 million so that the great bulk remains to come. The fiscal programme contemplates using about $3,300 million more by June 30, 1956.

It is impossible now to segregate how much of this staggering expenditure will be for hydro-electric power, but a large sum has been and will be allocated to this phase. Interagency also is dealing actively with flood control, irrigation, navigation, conservation of fish and game, public recreation, supply of water for human and industrial uses, and lately with extensive agricultural aspects. The latter includes notably a basin-wide plan to hold the soil where it belongs, instead of letting it wash down the rivers in the form of silt, and to go back to the very sources of the brooks and creeks in controlling the water.

The plan calls for 138 reservoirs behind dams in the Missouri and in lesser streams, with combined storage capacity of 110 million acre-feet of water—a volume enough to cover all England to a depth of about 40 inches. The larger dams will have hydro-electric plants, but the initial and ultimate generating capacities to be installed has yet to be decided. However, the official publication of Interagency's fiscal plan in September, 1949, declared: "Wherever practicable, hydro-electric plants will be constructed in conjunction with the proposed dam and reservoir projects. These plants will be provided with an ultimate installed capacity of two million kilowatts." By general understanding in the Missouri basin this means an eventual annual output of about 10,000 million kilowatt hours of current. "Ultimate" is a broad word, however, and just when the aggregate capacity may actually be in service remains undetermined. There is some question, even among some of the Federal officials concerned, as to whether the present plans would realize the full potentialities of the basin in hydro-electric production. Some critics of the present plan, who prefer MVA, have sought to show that the basin could yield as much as 18,000 million kilowatt hours a year.

One of Interagency's own members, B. H. Greene, regional chief engineer for the Federal Power Commission, in fact told the committee in August that the present plans called for installed generating capacity of three million kilowatts, producing about 14,000 million kilowatt hours annually. In contrast, he said physical potentialities of the stream are big enough to handle about five million kilowatt capacity, pro-

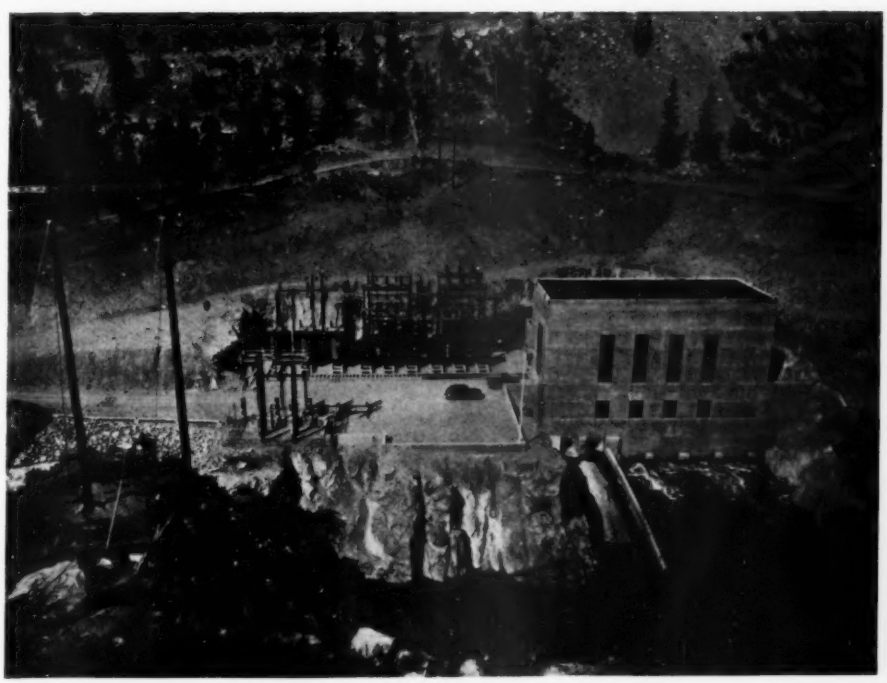
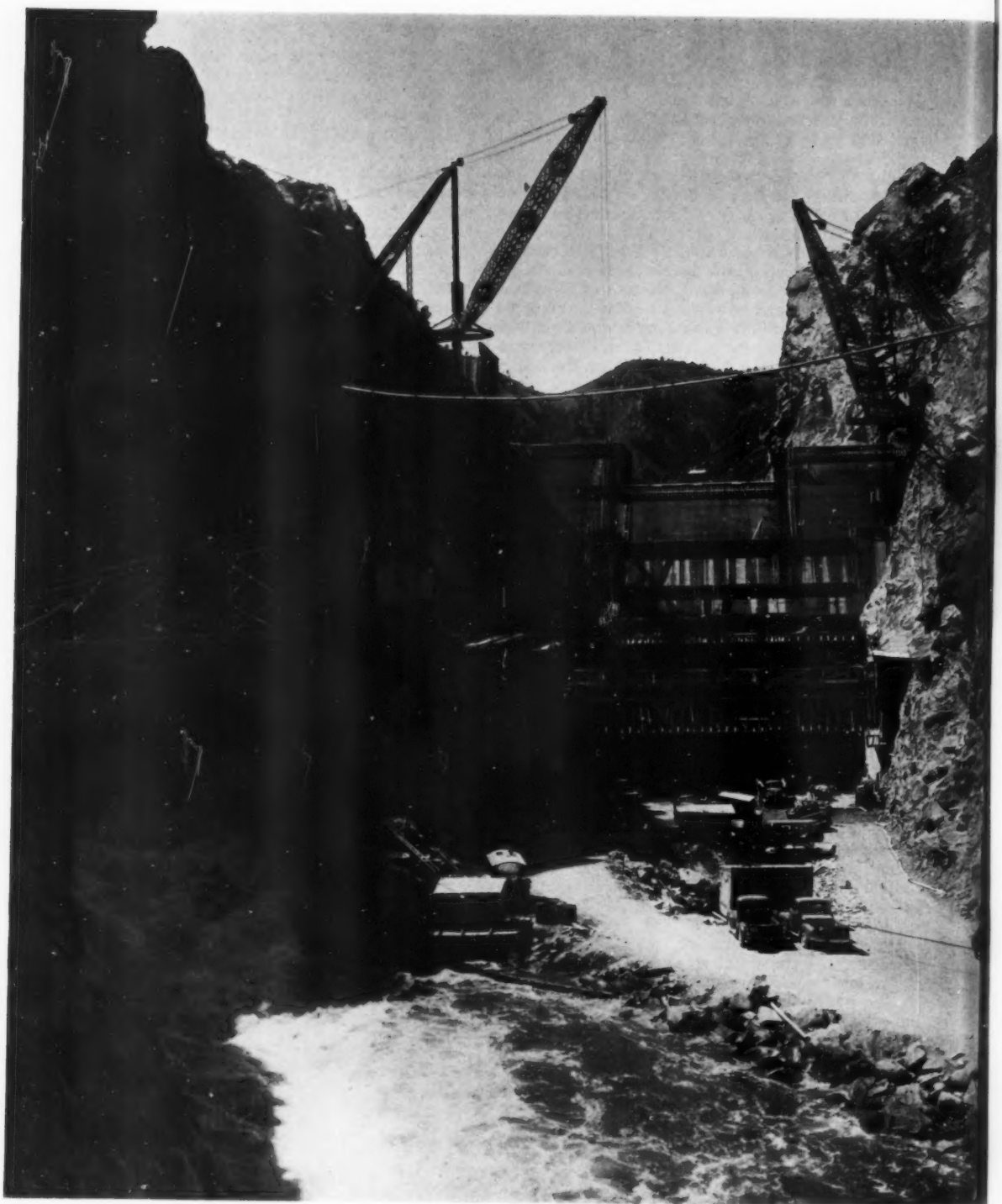


Fig. 7: Green Mountain power plant. A part of the Colorado-Big Thompson diversion—operating in Colorado on western slope of continental divide (within Colorado river basin)



Kortes dam in Wyoming nearing completion

ducing about twenty-five to thirty thousand million kilowatt hours annually. Obviously, other demands for water might make it difficult if not impossible to realize full physical potentialities for power generation. While the varying figures on capacity seem to illustrate confusion, they also emphasize the continuing character of the planning, the growing realization of the people of the basin what might be accomplished, and the ability of some of the Government representatives to recognize changes.

Some enthusiasts have talked about power dams across the Missouri river at its lower end, thinking of long structures stretching across the broad and fertile flood plain like some of those built by TVA. Their critics have replied that the fall of the stream is too gradual at this end to sustain any appreciable power plant at places such as Jefferson City, Missouri. On the other hand, some sober thinkers have continued to consider the possibilities of downstream power facilities.

Interagency's plan provides for seven dams across the Missouri river proper, all with power plants and all in the upstream section. One of these dams is built, four are under construction and two are in the active planning stage. Several of them are tremendous individual undertakings, whose statistics excite the imagination. Moving upstream, these dams come in the following order (latest figures for hydro-electric installed capacity are given):—

GAVINS POINT, in Nebraska and South Dakota, in planning stage; 80,000 to 100,000 kilowatts proposed.

FORT RANDALL, under construction in South Dakota; 160,000 kilowatts initially, 320,000 eventually.

BIG BEND, in South Dakota, in planning stage; 120,000 kilowatts eventually.

OAHE, early phase of construction under way in South Dakota; 140,000 to 250,000 kW initially, 400,000 to 490,000 kW eventually.

GARRISON, in advanced construction in North

Fig. 8 (above): Penstocks to Estes Park power plant which is part of the Colorado-Big Thompson diversion in Missouri River basin. The widely known summer resort of the same name is in the valley in background

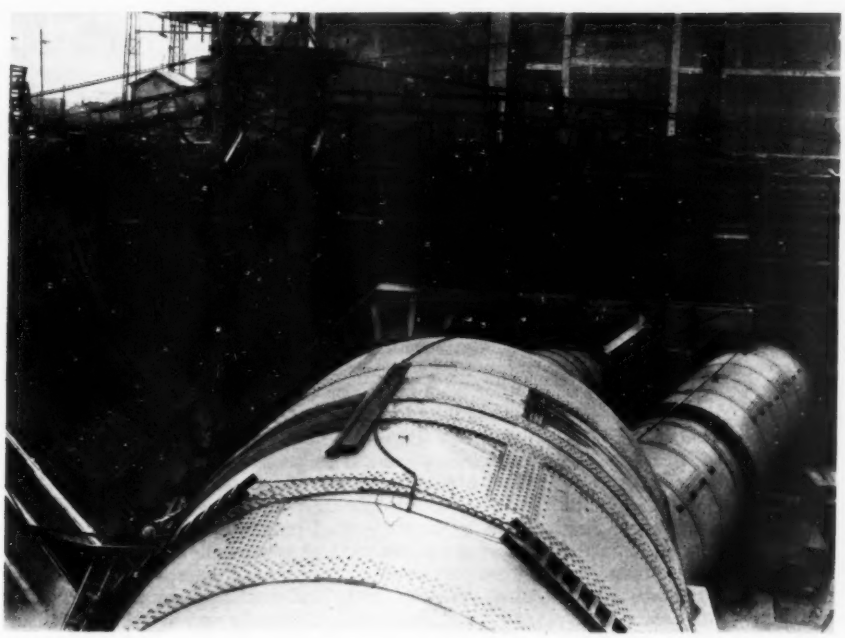


Fig. 9 (left): Installing penstocks at Fort Peck. The view shows forms and concrete placing set up for the south end of the 8 ft. thick wall upstream of the riser shafts

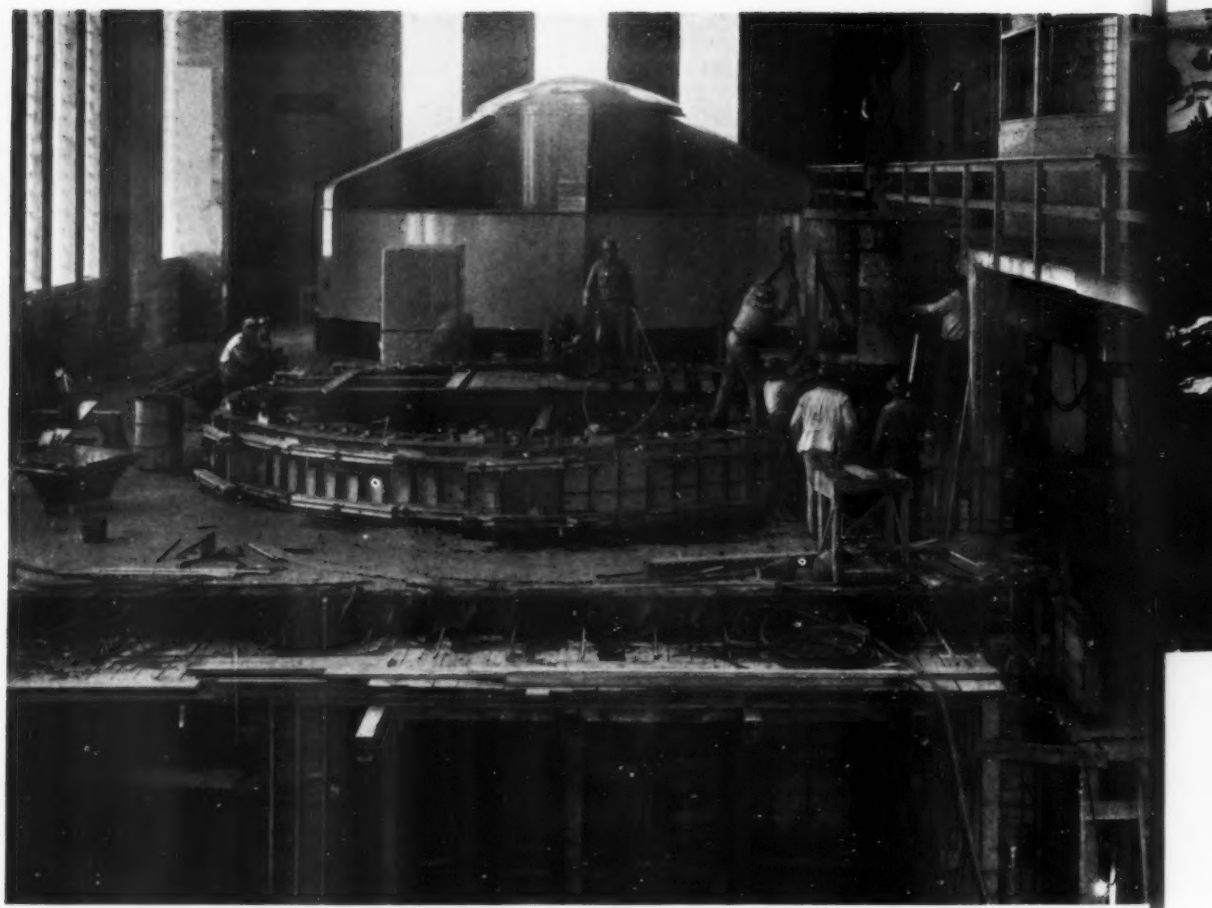


Fig. 10: Installing the second generating unit now in operation at Fort Peck. The photo shows concrete placing operations for cover curb wall of generator

Dakota and scheduled for completion in 1954; 240,000 kilowatts initially, 400,000 kW ultimately. This is the biggest and most costly single feature of the whole basin plan. Its reservoir will hold 23 million acre-feet of water. It is an earth-fill dam two miles or more long.

FORT PECK, built in eastern Montana in 1933-37 as a public works job in the depression. This is almost as big as Garrison. Fort Peck has generating capacity of 50,000 kilowatts which is now being increased to 85,000 kW. Ultimate capacity is planned for 105,000 to 185,000 kW. Some of the power facilities were just being completed in 1949.

CANYON FERRY, under construction, near the source of the Missouri proper in Montana; 50,000 kilowatts.

Some of the larger dams built, being built or to be built on tributary streams will also have power plants.

Competent engineers have estimated roughly that about 20 per cent. of the public power output in the Missouri basin would be required for pumping irrigation water, thus not going into the general grid for domestic and industrial use. While much of the impounded water in the reservoirs destined for irrigation will have a gravity flow to the farm lands, some pumping will be required, both out of the reservoir supplies and from wells. A notable instance of pumping will be a proposed eighty-foot lift to move water diverted from the Missouri river below Fort Peck Dam out of the Missouri basin and into the basin of the Red River. Work will soon start on the small diversion dam. Incidentally, the diversion scheme contemplates that the flow of additional water in the Red River will end just about inside the Canadian border.

It is recognized by all interests that the entire hydro-electric power production in the Missouri basin cannot be " firm," because of vagaries of the weather and the seasons, and the need for water for other purposes. While it is true that all electric power of importance now produced within Montana, both publicly and privately, comes from hydro plants, thanks to the proximity to the mountain ranges and their heavy snows, no such good fortune is possible farther downstream.

It has been only since last spring that Interagency officials have admitted publicly the necessity for considering construction of steam plants to assure a firm supply; but no definite steps towards getting them have yet been taken. In August, Governor Val Peterson (Republican) of Nebraska, who is chairman of

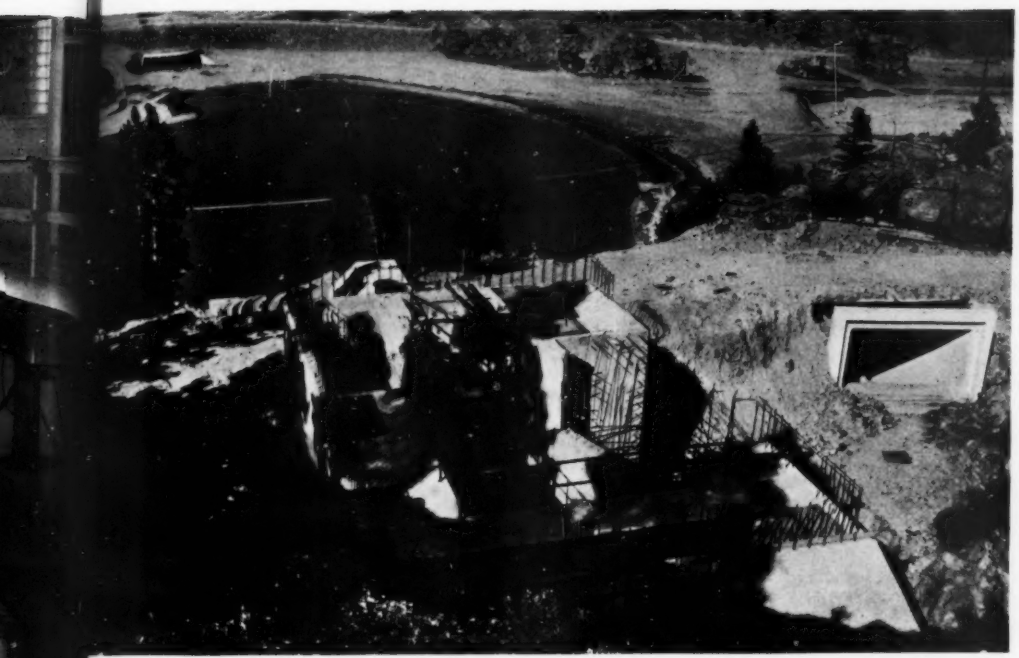


Fig. 11: The power plant at Mary's Lake under construction. This project is within the Missouri River basin and is part of the Colorado - Big Thompson diversion

the Missouri basin governors' committee, told Interagency he understood the basin would have a power shortage by 1970 even with full hydro-electric development. Mr. Greene said that by about 1963 the present hydro plans would have to be augmented with more hydro facilities or steam or diesel plants. In the Missouri basin, and in other parts, efforts to develop for the general public good the publicly owned water power resources have been fought stubbornly by the private power industry. In the autumn of 1949 this section suffered a serious setback when Congress voted funds for a public power plant at Canyon Ferry Dam, for important transmission lines connecting with Fort Peck Dam, and for other facilities.

Much of the opposition from the private power industry has been over public distribution of the publicly produced power. The industry wants to take it over at the station for distribution. The Federal Government's policy, however, is for transmission wherever possible by the Bureau of Reclamation or other agencies of the Department of the Interior, so that municipal distribution systems and rural electric cooperative associations can be served. In the case of Canyon Ferry Dam the Montana Power Company went even farther and tried hard to prohibit the Bureau of Reclamation from even building a power plant at the dam. The M.P.C. wanted the Government to build the dam and let the company construct and operate the power plant and control the product.

No opportunity or site of importance is left for private utilities to construct more hydro-electric plants, nor is there any manifest desire on their part to do so. They would rather let the Government make the huge investments required, then bargain for as much of the output as they can get, as cheaply as possible. Meanwhile there is a real and growing demand for power, and all the economic reports and surveys point strongly to the greater use of power throughout the Missouri basin, if it could be obtained.

There are interconnections of the power grids, both public and private, within the Missouri basin and with the adjoining Pacific Northwest, where Grand Coulee and Bonneville dams are among the big sources. The consumption of electricity has been so great, however, that in the winter of 1948-49 electric clocks in the Dakotas ran slow because of power shortage on the Pacific coast. Intensive studies of the power market in the Missouri basin have been made and published by the Federal Power Commission. They show the remarkable growth of domestic use of current, in the towns and on the farms, and the numerous opportunities for building up new industries. Recently, large phosphate deposits have been found, for instance, but no power is available to work them; and there are big deposits of low-grade manganese, where more power would help.

A new study of hydro-electric generating possibilities has been started by the Federal Power Commission and may be issued soon. Typical of the power situation is the Big Horn river sub-basin in Wyoming, most sparsely settled State in the Missouri valley. A Bureau of Reclamation official reported in September that the increase in power demand in this limited area had been "fantastic." Consumption there was one million kilowatt hours in 1922, he stated, but it is 100 million kilowatt hours annually at present, and the estimated need by 1960 is 250 million kilowatt hours.

Some of the Interagency power supply is coming already, and there will be more later, from the Colorado—Big Thompson Diversion. This is a project near Denver, Colorado, for shifting irrigation water from the Colorado river to the Missouri basin. The incidental power plants are intended to have a total of 177,400 kilowatts installed capacity and to produce 675 million kilowatt hours annually of firm power and 180 million kWh of secondary power. Plans have been started for even bigger diversions to the south.

French Tidal Projects

By F. J. de VOS. Consideration is given to the prospects of developing tidal power, particularly on the Brittany Coast. The tidal cycle systems are discussed in some detail.

L'article ci-dessous traite de l'utilisation éventuelle de l'énergie de marée en France, et plus particulièrement sur la côte Bretonne. Le Service d'Etudes sur l'Utilisation des Marées (S.E.U.M.), département de l'Electricité de France, étudie trois projets: celui de l'estuaire de la Rance, le projet d'usine de Chausey et celui de la double baie de l'Arguenon et Lancieux. Quelques détails sont donnés sur les cycles d'utilisation et sur les installations prévues pour la Rance. L'auteur exprime ses remerciements à l'UNESCO, à la Direction du S.E.U.M., au Laboratoire Dauphinois d'Hydraulique (Neyrpic) à Grenoble, ainsi qu'à toutes les personnes grâce à l'aide desquelles il a pu étudier le problème de l'énergie de la mer en France.

El artículo siguiente versa sobre la situación de Francia respecto al uso probable de la energía de las mareas, especialmente en la costa de la Bretaña francesa. El Departamento de Investigaciones Científicas sobre la Energía de las Mareas (S.E.U.M.), constituyendo un departamento de " L'Electricité de France," se está ocupando del estudio de tres proyectos: el relativo al estuario de Rance, el de la instalación Chausey y el de la bahía doble de Arguenon y Lancieux. El autor expresa su agradecimiento a Unesco, al Directorio de S.E.U.M., al Laboratoire Dauphinois d'Hydraulique de Grenoble y a todas las personas cuya ayuda le permitieron el estudio de los problemas relacionados con la energía de las mareas en Francia.

THE attention of French engineers has been directed for some years to the potential value of tidal power as a means of reinforcing the national supply of electrical energy, and an intensive study has been made of the possibilities of working certain of the estuaries on the French coast for this purpose. There is a large rise and fall of the tides along the whole of the channel coast, culminating in the maximum tidal range at St. Michael's Mount Bay where, in the case of the equinoctial spring tide (when the sun is in or near the vernal or autumnal equinox point of the ecliptic), it amounts to 41.3 feet. This figure is exceeded only in three places in the world —the Bristol Channel (British Isles) with 43 feet; the Bay of Frobisher, near Baffins Land in Canada, with 44.6 feet; and in Fundy Bay on the border of the United States and Canada where the range is 44.6 feet.

The Breton coast is a broken form with many freakishly shaped creeks, thus providing the conditions suitable for the construction of tidal basins.

In one place near Abervrach the building of such a scheme was started in 1928 (see Fig. 1), but lack of finance caused operations to be suspended in 1930. Here and there some *moulins à marées* are still existing (see Fig. 2). By the closing direction of the doors in basin H a high level is maintained, in basin L on the other hand a low level. T represents the turbines that utilize the fall. By choosing the dimensions correctly a practically continuous working of the turbines can be obtained. These installations form a poor symbol of the enormous powers, the exploitation of which has so far remained an unattainable ideal for mankind. Some idea of the magnitude of the tidal power available can be gained from a consideration of the theoretical quantity of energy that might possibly be produced by each tide per unit of surface of area enclosed, which equals the product of the square of the tidal amplitude and the specific gravity of the water, if all the energy could be extracted without loss up to the moment that the turbine fall equals the tidal difference.

Suppose this tidal difference to be 30 feet, it follows that the 705 tides experienced annually might produce altogether about 83 kWh per square yard; and since the consumption of electricity in France amounted to about 700 kWh per head annually in 1947, that was about 1/24th of a kWh per square yard of land surface, it is evident that one square yard of sea surface could supply nearly 2,000 times as large a land surface with electrical energy. On considering how much energy a mountain massif of 3,000 feet in height, with a rainfall of one yard per year, can produce, we find that this amounts annually to about 1.8 kWh per square yard; so that one square yard of sea surface produces about 45 times as much energy as that available from one square yard of mountain surface. These calculations, of course, are entirely theoretical.

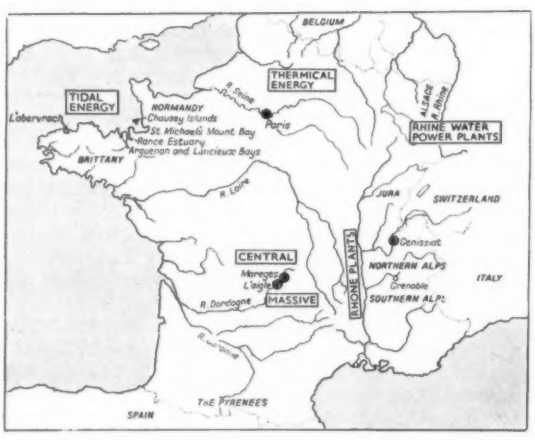


Fig. 1: Energy resources of France

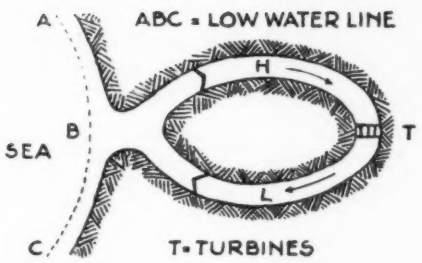


Fig. 2: Moulins à Marées

It appears that by utilising tidal energy in a basin working only when being filled or when being emptied, about 30 per cent. of the gross quantity of energy can be won; but in these circumstances a discontinuous supply only is available. In order to obtain a more continuous production of energy the basin could be put into action during filling as well as during emptying, by which means its output may be raised to about 40 per cent. If the nature of the territory is suitable a system of two basins can be employed, in which case one basin has a low level, and the other a high level; and when the basins are arranged to co-operate a utilisation of about 33 per cent. of the theoretical quantity of energy is possible.

In addition to the daily inequality of energy supply as a result of the shape of the tidal curve, there is another periodical variation that has an influence on the energy output—it is the phenomenon of neap and spring tides. In Fig. 3 the y-axis indicates the tidal coefficient, which is a measure of the magnitude of the tidal disparity (on the basis of an equinoctial spring tide having a coefficient of 100). Along the x-axis the time is indicated in which the high water belonging to every tide appears. It may be mentioned here that it is important to establish that the erection of the civil enginering works for a given tidal power scheme does not interfere with the tidal movement itself. The phenomenon of resonance might be brought into play by the erection of such works.

The regime of the tides is of a totally different nature from that of the rivers; there are no dry or wet years, no dry and no wet months, nor is there any influence of summer and winter upon the availability of tidal energy, and the inequalities due to the neap and spring tides and other matters are known and predictable. In a country partially or totally dependent on thermal energy, tidal power stations would not afford an economy in respect of a substitution for thermal power stations required to supply peak loads in winter time; the only economy would be in the consumption of fuel. In France, however, power generation in 1946 was shared almost equally by hydro-electric and thermal stations, and these figures are likely to be 60 per cent. and 40 per cent. respectively in 1952; thus the problem is of a different nature.

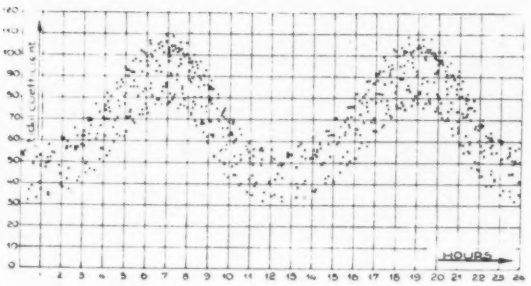


Fig. 3: Time-variations of high water at St. Malo The regime of the tides can be predicted

The only critical periods are the dry and cold winters, and as nearly all hydro-electric stations are equipped with day storage, the rather small river potentials may be concentrated on the peak hours, so that the supplying of the peak period is not the element that determines the thermal installation required to supplement the hydro-electric plant in dry and cold winters. Thermal power stations are working at full load during fourteen hours a day in the dry seasons; thus they are not fully utilised during the ten night hours. During the fourteen hour period, peak load is covered by the hydro-electric stations. It is not, therefore, the peak, but the average of the energy to be supplied, which is considered in determining the capacity of future thermal power stations. If season accumulation is available, even the criterion for the installation of thermal power stations is no longer the kWhs of production during fourteen hours of one particular day, but the production for a four-

Fig. 4: The Rance estuary, the chain-line shows the place for a further barrage

Fig. 5: Model in concrete of the Rance estuary without water

teen hour day averaged over a period much longer than a month; and in this period falls the whole neap-spring tide cycle. If tidal schemes were installed there would be no objection to emptying the hydro-electric reservoirs during the neap tide, provided that economic use of them is made during the spring tide period, because the regular return of the tidal cycle is assured.

If therefore the installation of tidal power stations is covered by seasonal reserve of storage capacity in the hydro-electric stations, the fluctuations in energy supply during neap and spring tides is completely neutralised, and has no influence at all upon the installation of thermal power plant.

The present energy policy in France aims, in the first instance, at considerably increasing the seasonal reserve available in connection with the hydro-electric stations. A tidal power station can supply nearly the same quantity of energy every lunar month, of which quantity, even if there is no flexibility at all, 14/24ths falls within the critical hours of the day; thus the contribution of such a scheme is as great as that of a thermal power station with a capacity equal to the mean capacity of the tidal power station. It will be seen that with an annual production of N kWhs, the building of a thermal power station of $\frac{N}{8760}$ kW becomes superfluous, and this amount can be increased by some flexibility in the regulation to enable a greater part of the energy production to fall within the critical fourteen hour period.

Studies made by the S.E.U.M.

The *Service d'Etudes pour l'Utilisation des Marées*, a body associated with the nationalized *Electricité de France*, has collected a great amount of documentary evidence about tidal power possibilities; it has examined the French coast, and finally put forward practicable plans. The results of these studies were examined by an inter-departmental committee, the *Comité Technique de l'Energie des Mers*, which rejected all small projects and concentrated on three plans: the estuary of the Rance, the St. Michael's Mount Bay (Chausey Islands Scheme), and the double bay of Arguenon-Lancieux (see Fig. 1).

The figures relating to these schemes are shown in the following table, where A and S refer to an equinoctial spring tide and high water:—

The Rance project especially shows favourable values for $\frac{L}{S}$ and $\frac{L}{E}$ Thus a further study of the Rance estuary has been undertaken, and Fig. 4 shows some details in this connection. The different methods possible for closing the basin are being examined. The tidal disparity and the depth, which varies from zero to 33 feet below the lowest water level, has given rise to considerable difficulties. It is hoped that these studies will provide assistance to the engineers who examine the even greater difficulties awaiting them when considering the closure of St. Michael's Mount Bay.

It is certain, in regard to this latter scheme, that nothing will injure the architecture of the famous St. Michael's Mount, because the works are planned nearer to the Chausey Islands than to the Mount. Fig. 5 gives an impression of the freakish nature of the coast-line at Rance. The model shows the shape of the bottom, the borders, and the islets, but it must be realised that the scale of elevation is 1 to 80, and the horizontal scale is 1 to 500.

1.—SINGLE CYCLE SYSTEM: Only about half the tidal energy is exploited by this system. A basin is either filled through sluices by the rising tide and emptied at about the low water period through the

TABLE I.

Name	Amplitude A (in feet)	Surface S (in acres)	Natural energy quantity E (10^6 kWh/year)	Dam Length L (in yards)	$\frac{L}{S}$	$\frac{L}{E}$
Rance - - -	37	5,700	2,010	790	0.15	0.39
St. Michael's Mount Bay (Chausey Islands Scheme)	41	140,000	60,000	19,600 + 16,400 = 36,000	0.26	0.60
Arguenon-Lancieux	37	6,800	2,520	6,900	1.01	2.75

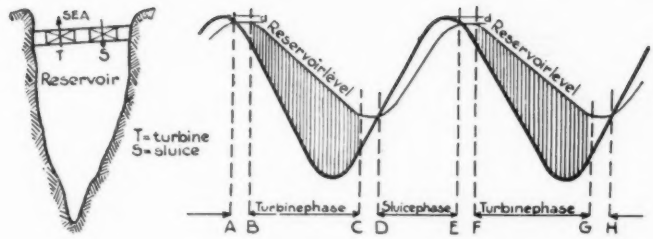


Fig. 6: Cycle of single utilisation of Tidal power during emptying

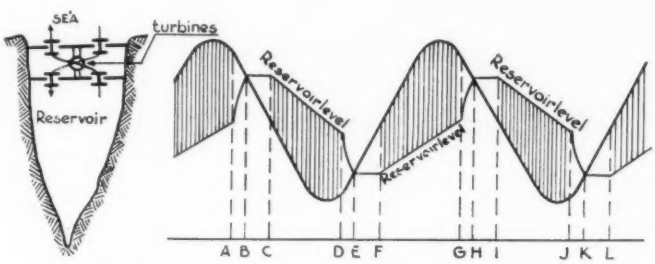


Fig. 7: Cycle of full utilisation of Tidal power

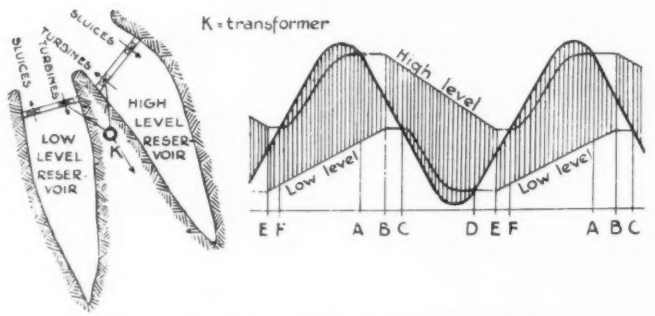


Fig. 8: Cycle of two partly co-operating reservoirs

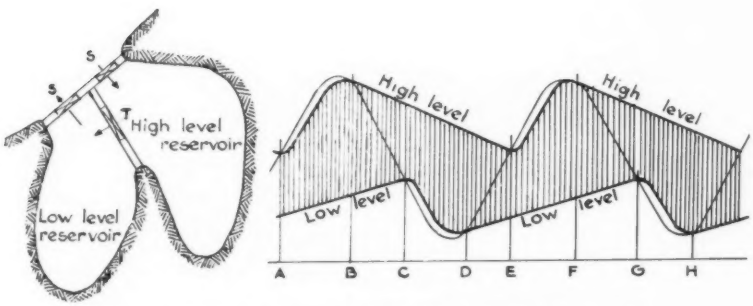


Fig. 9: Cycle of two completely co-operating reservoirs

turbines; or it is emptied at falling tide through the sluices and the basin filled through the turbines when the tide rises. As a result of the shape of the shores of a basin the effect of a system producing energy when being emptied is greater than that of a system having the turbine operating phase during the filling period. The ratio of the two quantities of energy is about 3 to 2 for the Rance. In diagrammatic form, a system of this type supplying energy during the emptying cycle is shown in Fig. 6. Here, in one diagram with the tidal curve, a line has been drawn representing the height of the water level as a function of time. The periods during which the turbines are working have been hatched.

2. — DOUBLE CYCLE SYSTEM: Tidal energy is utilised by this system on both filling and emptying cycles. Fig. 7 shows this condition. In order to create sufficient fall for the turbine phase it is always necessary to cause the basin to reach the required level by means of sluices at the end of the preceding generating phase. It is evident that in this system the availability of a very large sluice area is indispensable. Moreover, special construction work must be incorporated in the system to ensure that the water at all times runs in the same direction through the turbines. If the sluice surface is to be kept within reasonable limits, the water in the basin does not reach either high water or low water, as it was nearly the case in the single cycle system. Thus the energy provided for the Rance scheme is not 167 per cent. of the single cycle system, but is only about 118 per cent.

3. — THE TWO BASIN SYSTEM: In the first variation of this scheme both basins are operated with a normal single cycle, in which, however, one basin produces energy during filling and the other during emptying. In Fig. 8 the upper broken line shows the course of the water level in the high basin, and

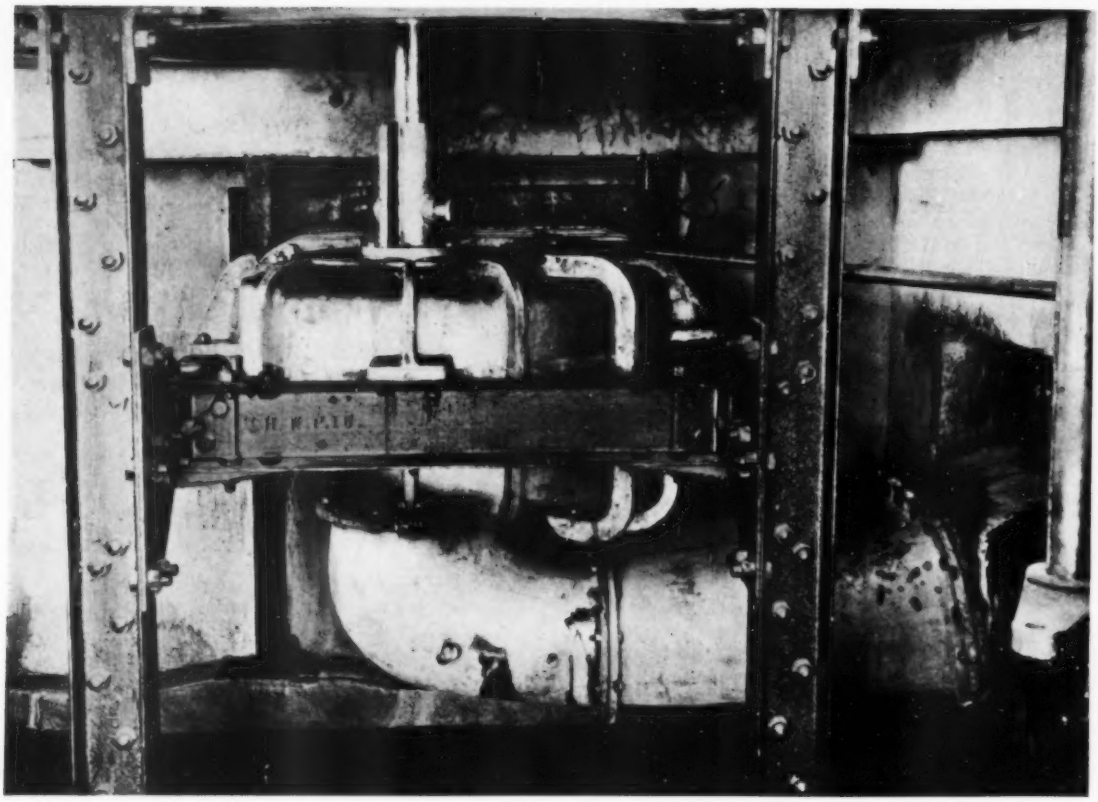


Fig. 10: Turbine or pump of the experimental installation at Grenoble

the lower broken line gives the same indication for the low basin.

A second variation makes two basins fully co-operative by placing turbines and the power station in the centre, thus employing them for both basins. Fig. 9 shows the level fluctuations in the basin, and it will be seen that during part of the turbine phase either the high or the low basin communicates with the sea *via* the sluices, which entails their being filled or emptied simultaneously. In this way there is a gain as regards the fall height, which explains why this cycle gives favourable results, although it is only applicable if natural circumstances permit.

From time to time other systems with two or more basins have been projected, all of them aiming at equalizing the variation of the fall, and consequently the energy yield. Because of the development of the turbine with movable blades—the so called Kaplan turbine—a large variation of fall is no longer so troublesome. This type of turbine is especially suitable for small heads and large discharges, giving a satisfactory performance even at a variation of head as low as 1 to 3.

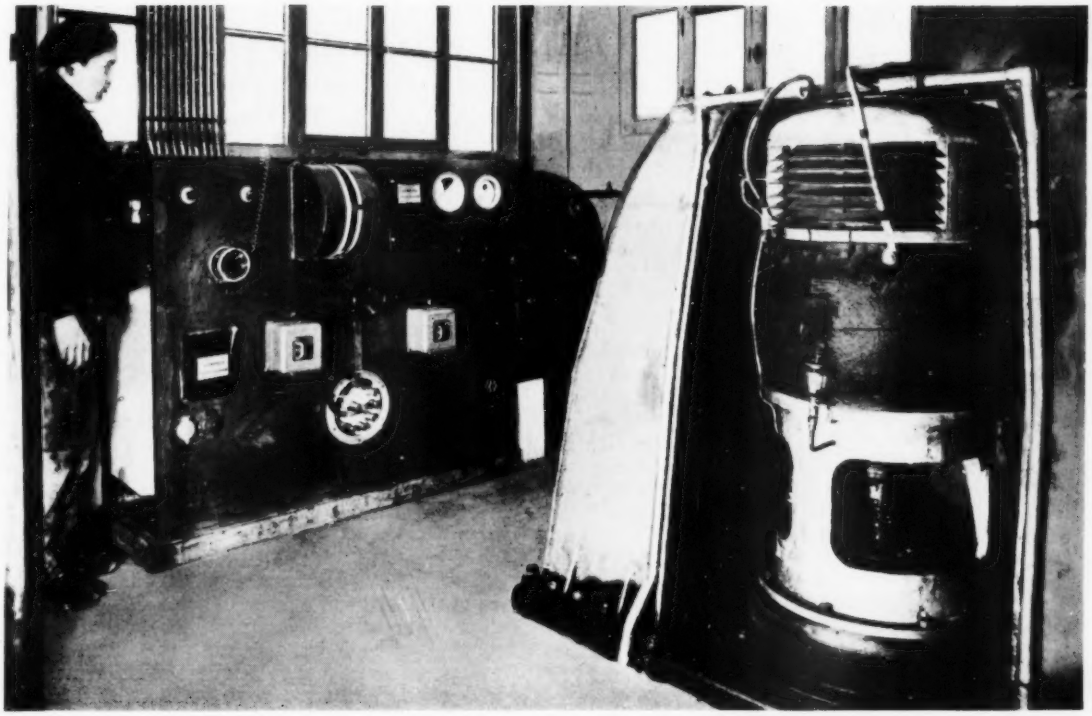
For the Rance scheme a cycle with single utilization of the tides during emptying has been chosen. For the Chausey Islands scheme, and for the Bays of Arguenon and Lancieux, the application of a system with two completely cooperating basins is under consideration. Moreover, there are plans which aim at employing the turbines as pumps as soon as the period of very low head renders their functioning impossible, with the intention of letting the water pumped up by this means flow out again through the turbines during the higher head period. This will considerably increase the yield, and at the same time prolong the working periods, as the minimum head for the operation of the turbines will be available sooner. For the Rance scheme this fall is about 4.6 feet.

At Grenoble, in the experimental station of the *Laboratoire Dauphinois d'Hydraulique (Neyrpic)*, the operating of turbines as pumps is being studied with a view to increasing their efficiency. Already a considerable improvement has been obtained, and Figs. 10 and 11 illustrate the experimental installation, Fig. 10 showing the turbine or the pump, and Fig. 11 the generator on the same shaft.

An important point in designing tidal power stations is the eventual possibility of cooperation with other installations along the coast. In this way it may be possible to make use of the different times of high and low water along the seaboard, which is due to the time taken for propagation of the tide. An equally time-spread energy supply, by means of appropriate combinations of tidal power stations, is thus envisaged.

Details of French Schemes

1.—THE RANCE SCHEME. Although not a simple project it has yet a definite character, nevertheless the most suitable installation for the Rance estuary has been devised. This scheme has been planned to contain eighteen vertical shaft Kaplan



units, each of 20,000 kW. The diameter of the runners will be 26 feet, and the maximum use of water will amount to about 420 cubic yards a second at a head of 23 feet (see Fig. 12). The surface of the sluices has been decided at 3,600 square yards. The yield of this scheme will not at the moment cover more than 2½ per cent. of the present consumption of electrical energy in France, amounting as it will to about 700 million kWh per year.

2.—THE CHAUSEY ISLANDS SCHEME has been based on a yearly production of 12½ milliard kWh. No definite plans, however, have yet been decided.

Theoretical studies are being made at the bureau of the S.E.U.M. in Paris, in cooperation with the *Laboratoire Dauphinois d'Hydraulique* at Grenoble. In the laboratory a concrete model (already mentioned), representing the estuary of the Rance, has been made, and research with it include the phenomena relating to disturbance of tidal movement, overfilling of basins, effects on bottoms and shores of different sluice capacities, and differing locations of the sluices. In the same laboratory there are also models of the Bays of Arguenon and Lancieux.

It is hoped that before long the investigations into the Rance scheme will be completed. Its cost will be computed and a decision made as to whether or not the plans are to be carried out. If the decision is favourable the first tidal power station in the world would probably start to supply current in about ten years' time.

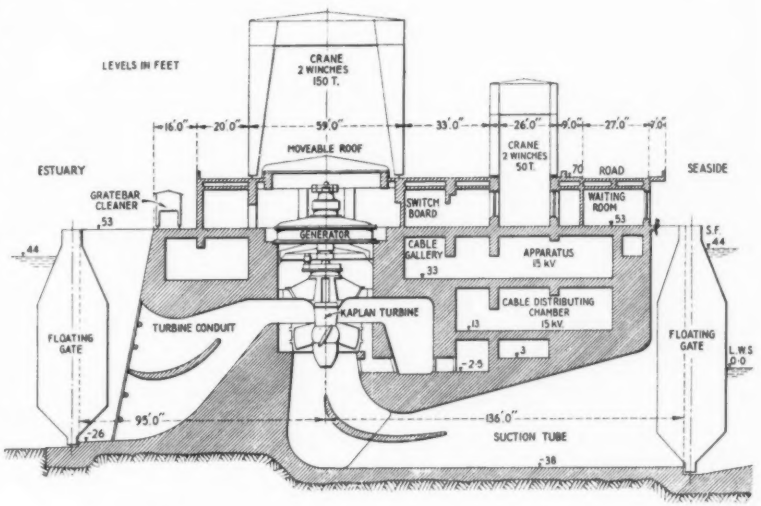


Fig. 11 (top): Generator of the experimental installation

Fig. 12: Section of the Rance turbine

The Scottish Scheme

During the currency of this issue the Clunie power station, which is part of the North of Scotland Hydro-Electric Board's Tummel-Garry project, is expected to start generating electricity. Our special correspondent here describes some of its features, including the associated dam and tunnel: the power house will be discussed in a subsequent issue.

CLUNIE power station forms part of a wider scheme to develop the hydro-electric potentialities of the rivers Tummel and Garry which form a total catchment area of 706 square miles to the north west of Pitlochry, in Perthshire. Of this total, 322 square miles are associated in the present project; the remaining 384 square miles have already been developed by the Grampian Electricity Supply Company. Both rivers are tributaries of the Tay and when the scheme for their development is complete they will contribute some 300 million kW hours to the nation's power requirements.

The new project is a logical development of the scheme initiated by the Grampian Company, which began operations in this region by impounding the waters of Loch Ericht and Loch Rannoch. These two stations which produce some 270 million kWh per annum were completed in the early 'thirties and are now, of course, controlled by the North of Scotland Hydro-Electric Board.

The part played by Clunie in this harnessing of water power will be most easily understood by reference to the sketch map reproduced in Fig. 2. From this it will be seen that a high-level reservoir will be constructed in the upper reaches of the Errochty, a tributary of the Garry, to form a new loch three miles long and situated nearly 1,100 feet above sea level. To augment the natural catchment area of this reservoir a series of aqueducts and tunnels will be constructed to carry the waters of the Bruar, Garry and other streams, thus diverting their waters from an area of 79.5 square miles. Water from

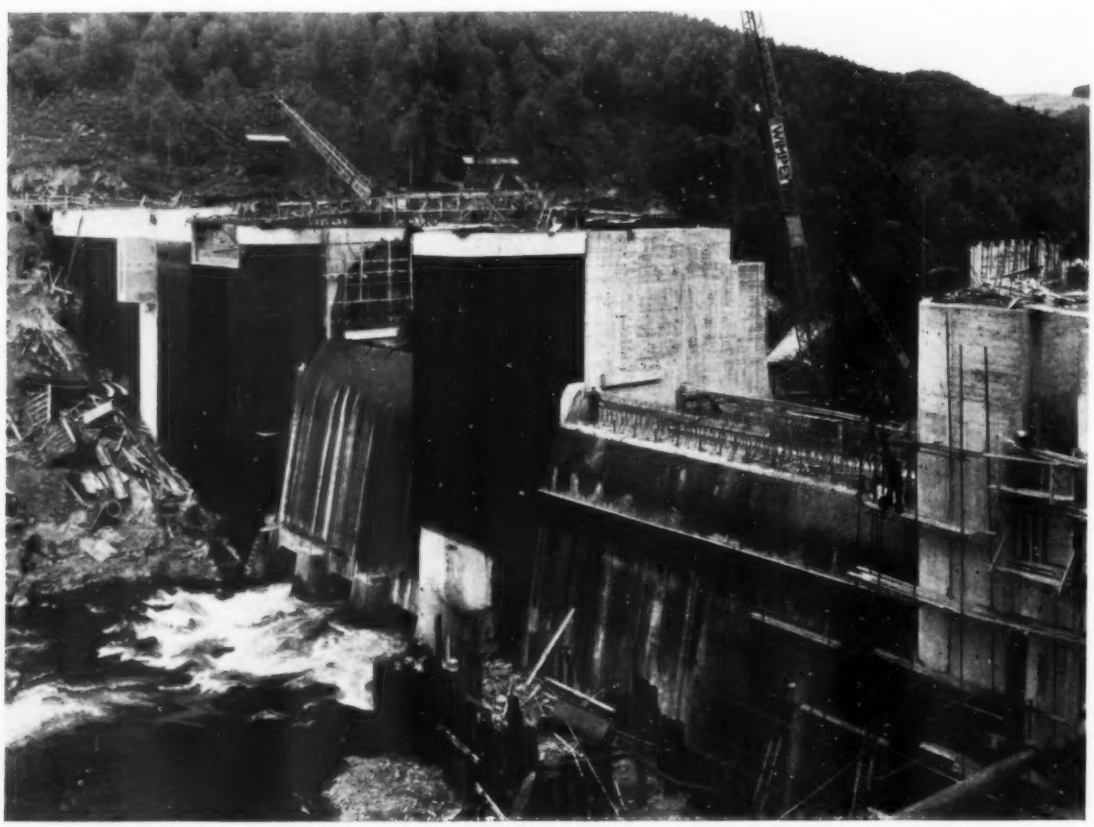


Fig. 1: General view of Clunie dam from right bank

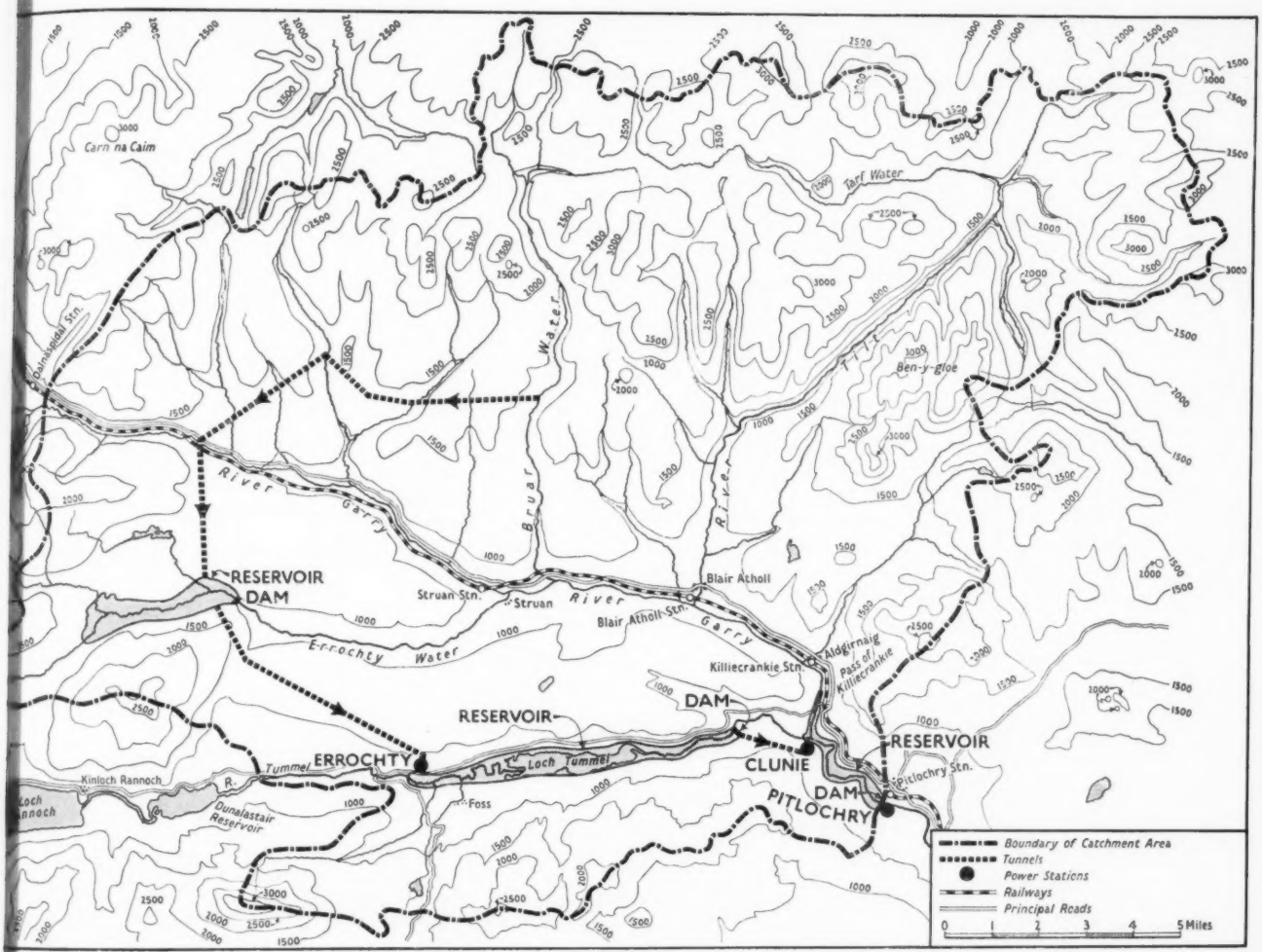


Fig. 2: Map showing catchment area and position of tunnels and power stations

the reservoir is passed by another tunnel nearly six miles in length to Errochty power station where three generator sets will be installed. The turbines are to be of the Francis vertical type and will be designed to operate on a gross head of 610 feet, the total installed capacity being 75,000 kW.

Errochty power station is situated near the western end of Loch Tummel into which, of course, the tail race discharges. This loch has also been impounded and it is to this end that the Clunie dam has been constructed to raise the level about 17 feet, which will have the effect of rather more than doubling the surface area. It is with Clunie dam and its associated tunnel that this article is concerned. The power station is so intimately linked with the new Pitlochry station about two miles downstream, however, that it is necessary to say a few words about the equipment there. Two 7,500 kW Kaplan turbines are scheduled to be put in operation in this station but both the generating plant and distribution of the current will be controlled from the larger Clunie station where the administrative buildings for both plants are situated.

A view of the Clunie dam is reproduced in Fig. 1. It is an impressive structure 386 feet long, having a maximum height of 65 feet, and occupies a gorge in the river Tummel; the maximum width, at the base of the spillway bucket section, is 90 feet including the spillway bucket. A conspicuous feature of the dam are the two drum gates constituting the spillway which automatically keep the loch at a constant level, and of which more will be said later. Operations were started by constructing a coffer dam of interlocking sheet-steel piling to enclose the northern half of the river bed. Behind this the river gravel was removed down to rock head, the soft, weathered material from the surface being removed and a portion of the bed-rock grouted. A cut-off curtain was also injected with cement under pressure to seal off any crevices or fault planes in the vicinity.

The rock encountered was Highland schist which is not normally suitable for aggregate; consequently the aggregate had to be brought from a quarry that was opened up at Bonskeid, about two miles away. This provided a fine-grained quartzite eminently suited to the purpose as regards strength and density though a little harsh because of its angular form. It

was delivered to the site crushed and graded in the following sizes—2½ in. to 1½ in.; 1½ in. to ¾ in.; ¾ in. to ⅜ in.; and ⅜ in. to 3/16 in. All the sand had to be brought either from Alyth, and Castlehill near Blairgowrie, or from Perth.

In determining the proportions of the aggregate and concrete impermeability rather than great strength was the governing factor and the exact amount of sand required was decided after searching tests. Generally the basis of the mixture was 20 cu. ft. of crushed stone to 10 to 12 cu. ft. of sand; to this bulk 3, 4, 5 or 6 one-cwt. bags of ordinary Portland cement were added according to the purpose for which the resulting concrete was used. For instance, in the heart of the dam four bags of cement were used with 20 cu. ft. of coarse aggregate consisting of material passing 2½ in. mesh downwards; whereas in all the faces in actual contact with water the mix was composed of six bags of cement to 20 cu. ft. of coarse aggregate containing particles not greater than 1½ in. In those portions of the structure requiring special reinforcement the mix consisted of six bags of cement to 20 cu. ft. of stone graded from ¾ in. downwards. This mix, for example, was adopted for those parts of the dam forming the recesses for the drum gates, which were reinforced with 1⅛ in. diameter bars spaced at 6 in. centres. As a check on the strength of the concrete, cubes were cast daily from the main pours and submitted to a crushing test in a laboratory erected on the site and provided with a 200 ton testing

Fig. 3 (above): Loading rock from intake heading, pilot tunnel

Fig. 4 (below): General arrangement drawing of Clunie dam

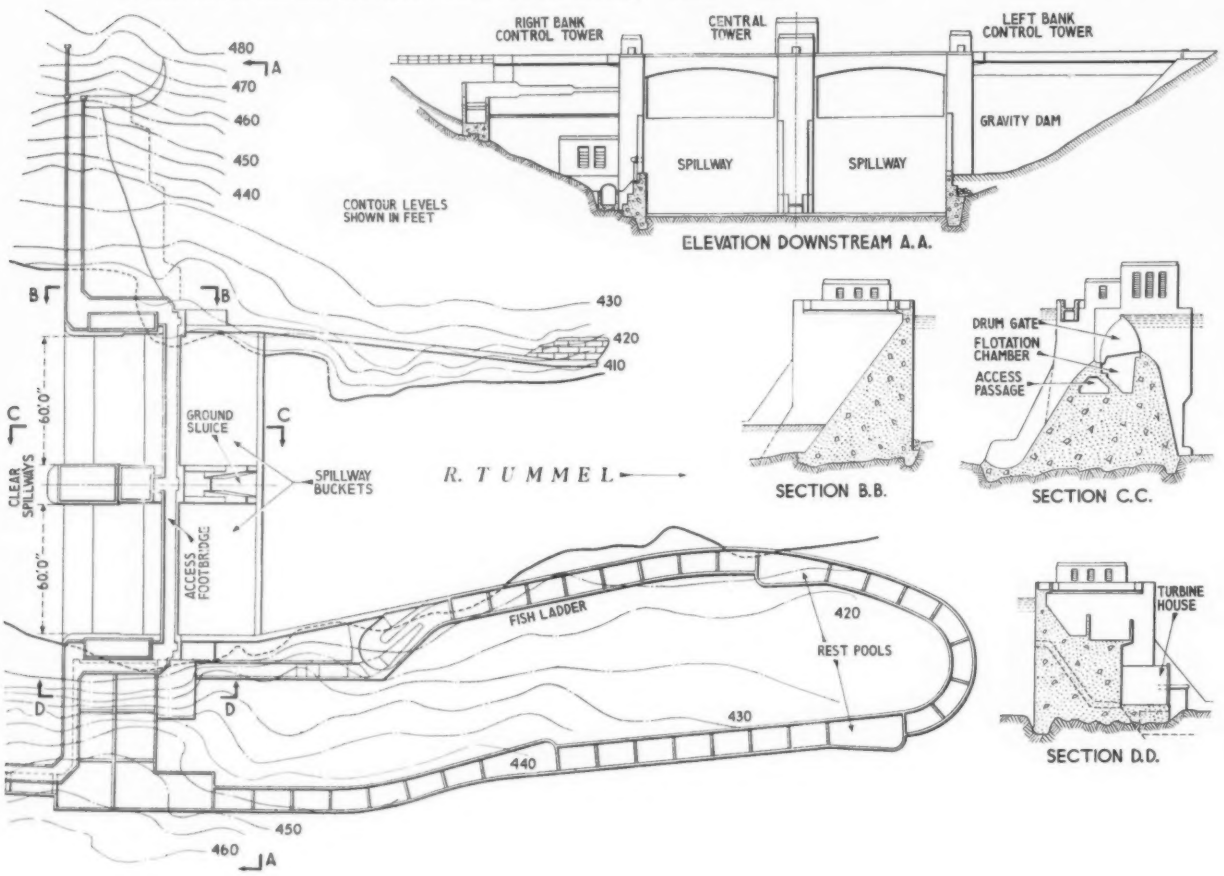


Fig. 5: General view of the horseshoe section of the tunnel showing arched steel reinforcements and ventilating duct

machine. Generally 6 in. cubes were prepared for these tests but for the aggregates containing 2½ in. material the cubes had 8 in. sides.

In all, about 40,000 cu. yards of concrete were used in the dam. The mixer was of 1 cu. yard capacity and the concrete distributed about the site by five derricks of 7 and 10 tons capacity, in addition to a number of cranes. In the early stages, for the plain and repetitive work steel shuttering was used comprising rolled-section soldiers and steel-plate panels but later timber was most commonly used. During the later stages of the work, when an accelerated programme was demanded, a Koehring Paver double-drum mixer was brought to the site. This machine was originally designed for the quick laying of airfield runways during the war and has a capacity of 30 to 35 cu. yards an hour (actually accomplished on the Clunie site) compared with an upper limit of 25 cu. yards an hour for the normal single-drum mixer. Its use in an operation of this kind would not normally be economic, but as a means of increasing the tempo of the work to meet an anticipated date the introduction of this machine by the contractors was fully justified, not to say enterprising.

Although some of the concrete was consolidated by immersion vibrators of American manufacture much was tamped by hand or by stamping. In using the vibrator, which consists of a flexible hose containing the vibrating element, care was taken to withdraw before any possibility of segregation took place.

All horizontal joints in the structure are staggered, the bond between successive layers being ensured by scabbling the surface with a hand tool and providing horizontal recesses or keyways with which the succeeding layers are interlocked. These recesses were formed by boxes of trapezoidal section and constructed of sheet steel or timber attached to wooden frames. No special precautions were considered necessary to prevent overheating of the concrete as ordinary Portland cement was used and sufficient time allowed to elapse between finishing one layer and superimposing another layer upon it. Experience has proved that with the height of lift adopted the heat loss due to radiation is quite sufficient to ensure that any detrimental increases in temperature do not occur

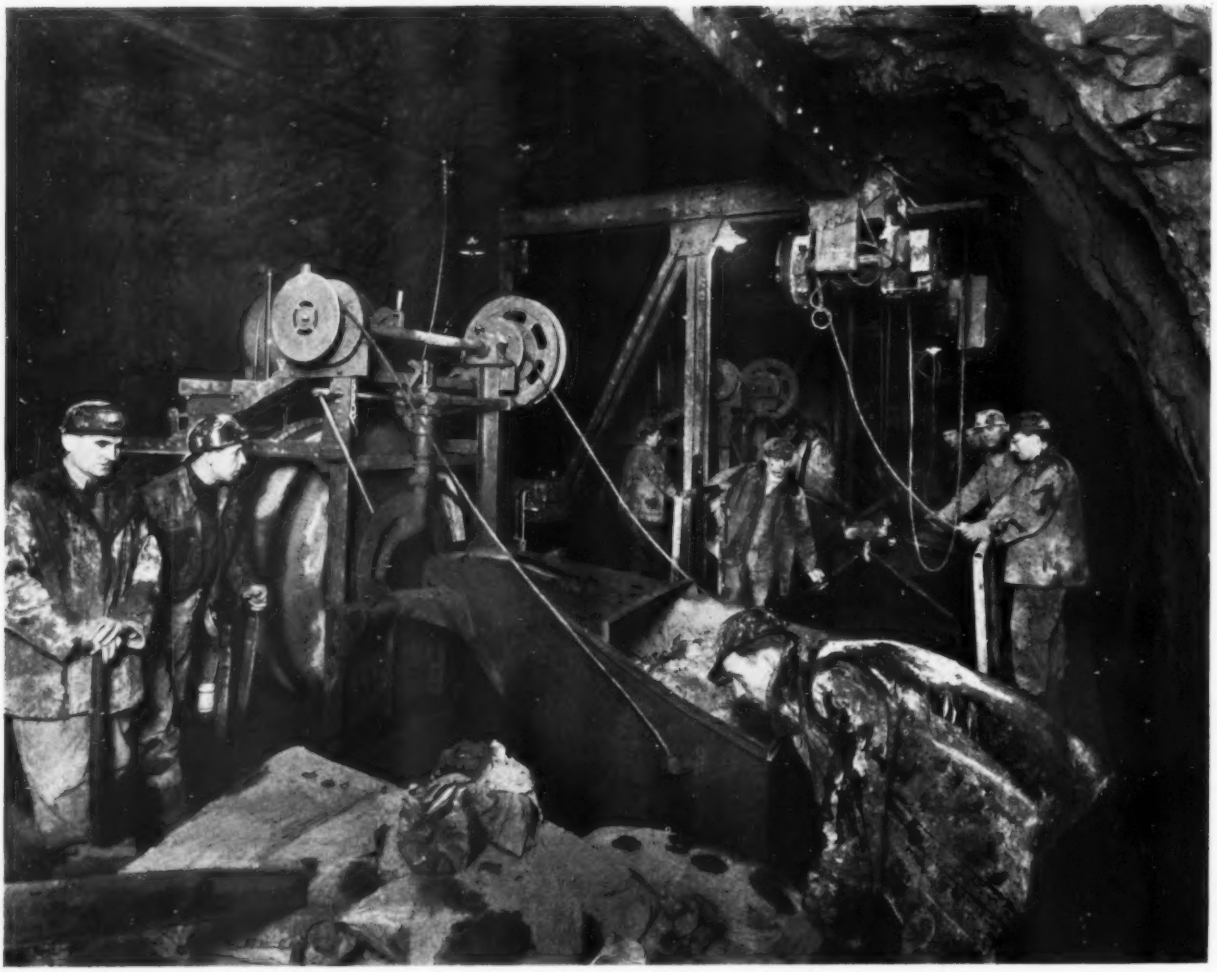
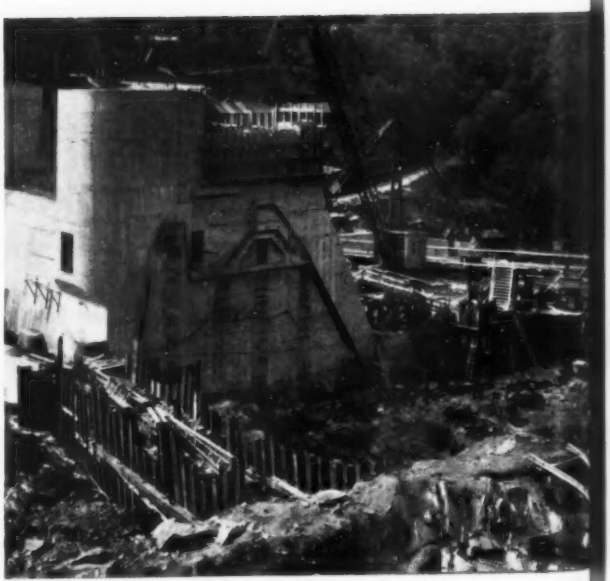


Fig. 6 (above): Materson remote-control travelling hoists supplying concrete mixers
Fig. 7 (right): Showing coffer dam on right bank

when this simple precaution is taken.

The vertical expansion joints in the spillways are sealed by U-shaped strips of copper, the bond between the concrete and that part of the metal embedded in the concrete at either side being strengthened by occasional perforations through the wings to enable the concrete to pass between. For a width of 3 in. around the U-shaped bend, however, a coating of bitumen prevents any bond, so enabling the copper strip to flex as the gap opens and closes. A precast bitumen filler strip was inserted inside the U bend to provide a cushion against expansion.



Spillway Drum Gates

The drum gates are shown in section in Fig. 16, from which it will be seen that they are hinged at the bottom upstream corner and float in a chamber formed in the dam structure underneath. Each chamber is provided with an inlet and valve set to a determined opening and the rate of outflow is regu-

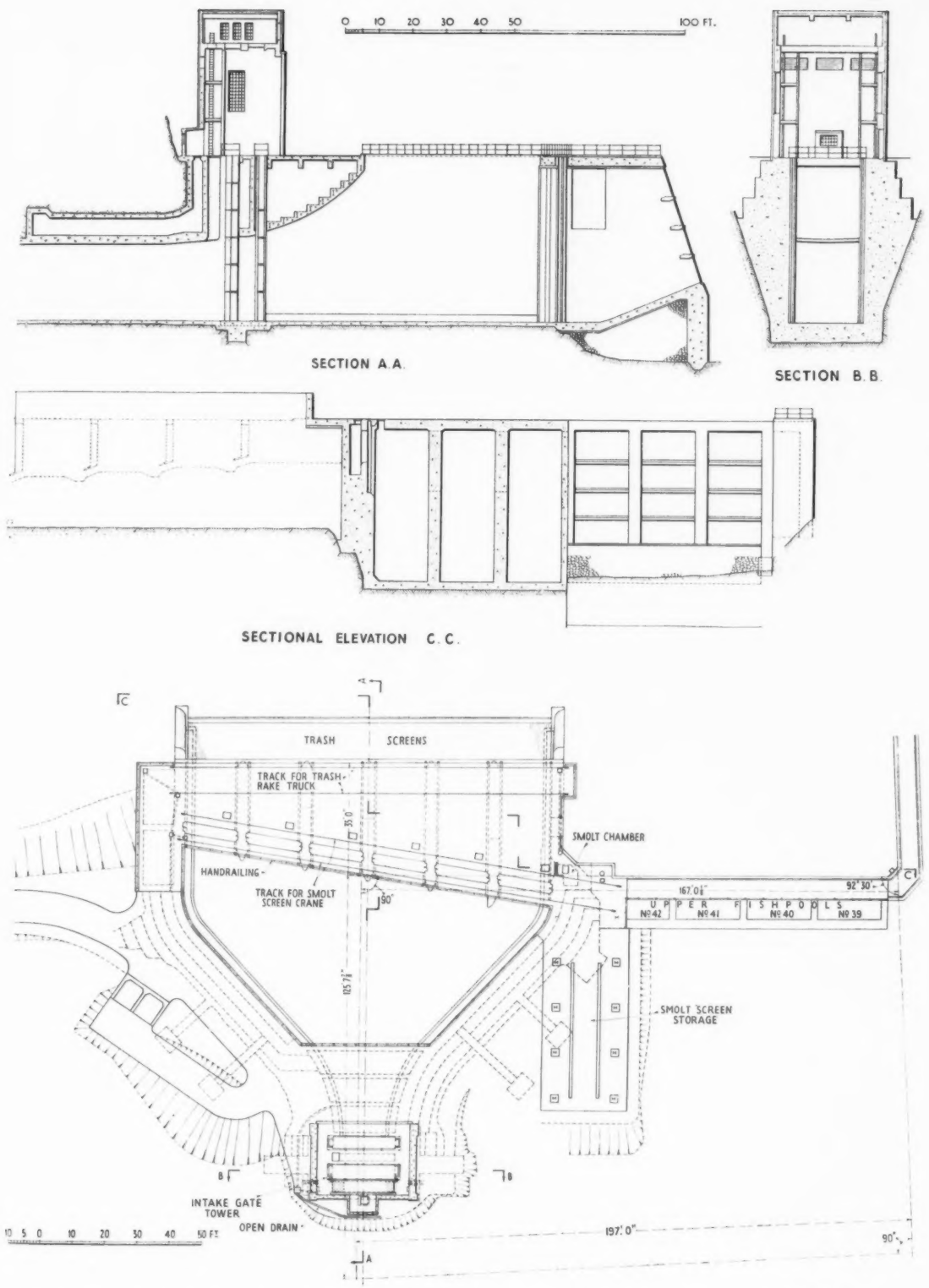


Fig. 8: Elevation and plan of intake showing relation between trash screens, smolt screens and fishpools

lated by a float-operated valve, the position of which is determined by the level of the water impounded in the dam. Accordingly, at times of flood, the actuating float rises and opens the outlet valve, so increasing the amount flowing out of the chamber, thus lowering the drum and increasing the depth of spillage. In periods of dry weather this process is reversed, the drum assuming a position appropriate to the unavoidable spillage to within very precise limits.

Several considerations influenced the adoption of the floating-drum-type crest gates. It was, for instance, deemed desirable from the amenity standpoint to limit the range of top water levels and as the dam is constructed in a narrow gorge any attempt to pass an estimated maximum flood discharge in the region of 30,000 cusecs. by an orthodox free spillway would have involved a considerable rise in the level of the impounded water. Conversely, if the maximum flood water level had been limited to the present determined top water level, a serious loss of storage and working head would have resulted.

While achieving these important advantages, the presence of drum-type gates, in comparatively low spillway dams, introduces special problems in connection with the design of the spillway face slope and bucket and the reinforcing of the gate chamber. To ensure maximum overall efficiency of operation, extensive model experiments were made to determine the nappe profile and pressure distribution for various angular deflections of the gates. The results of these experiments and other considerations indicate that the form of construction to be adopted, when drum-type crest gates are used with comparatively low dams, depends much upon the relation between the cross-sectional dimensions of the drum gates and their buoyancy chambers and the dam height, which relation has a distinct effect upon the downstream slope of the spillway face.

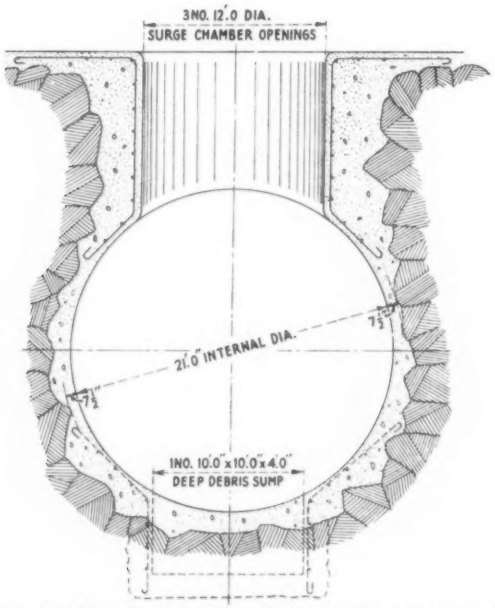


Fig. 9: Circular section showing one of the six openings to the surge chamber

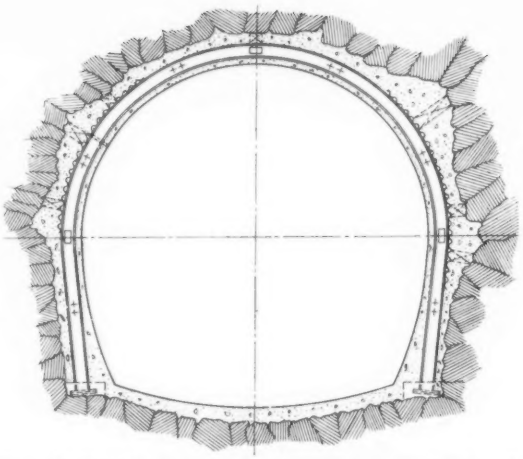


Fig. 10: Showing method of supporting unsound rock

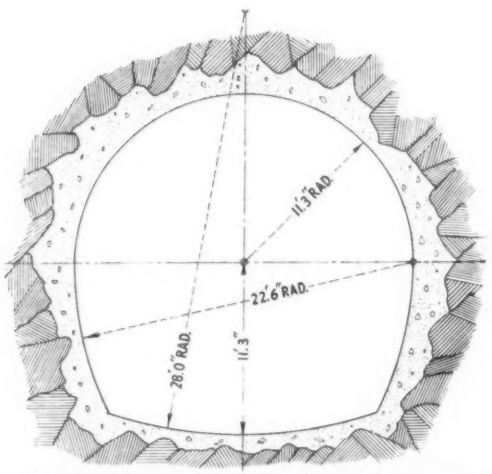


Fig. 11: Typical section of tunnel in firm rock

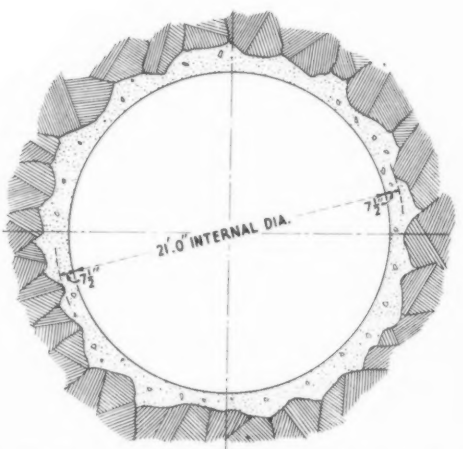


Fig. 12: Typical section of 21 ft. diameter circular portion of tunnel at outfall end

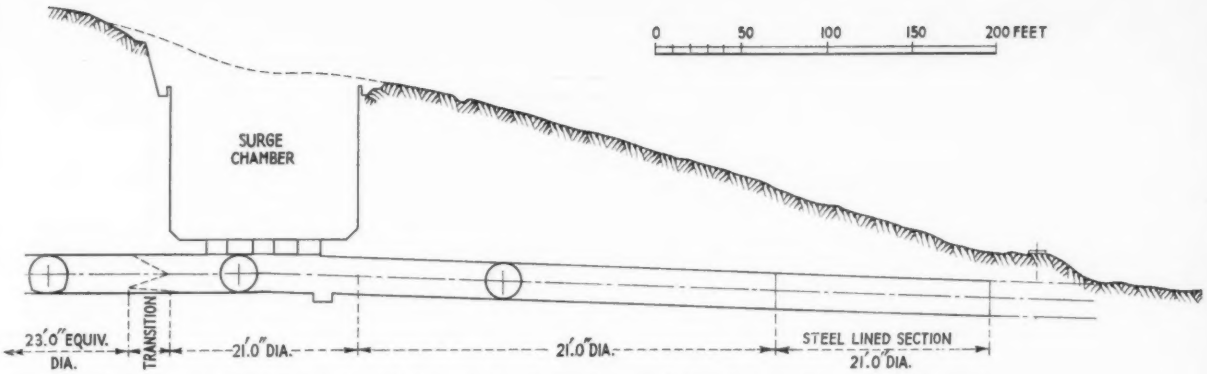


Fig. 13: Showing surge chamber in relation to the horseshoe and circular sections of the tunnel

At Clunie the resulting profile enabled some economy to be achieved by the construction of a hollow-type spillway, though a much higher dam would be necessary to justify a thin-slabbed Ambursen type of dam, owing largely to the peculiar structural requirements of the drum-gate chamber.

Particular interest attaches to the fish pass provided with this dam. To surmount the height of 65 ft. imposed by the dam a succession of concrete chambers has been constructed 18 ft. long, 10 ft. 6 in. wide and rising in increments of 1 ft. 6 in. It had to be constructed with a hairpin bend; and, as an additional precaution against the fish getting exhausted, three resting pools have been provided, each having about twice the volume of the normal chambers.

So much for the running salmon; for the smolts another series of precautions has been provided. In the first place the superficial area of the intake has been enlarged to twice the dimensions that purely engineering principles would have dictated. This was done to slow down the velocity of the water to such a point that there would be no possibility of the young fish being held against the mesh plates and unable to free themselves. The trash screens, which are fitted with $\frac{1}{2}$ in. by 3 in. bars spaced 2 in. apart and arranged for mechanical cleaning, enable the fish to pass freely through them. Well back from them are the smolt screens themselves, fitted with meshes $\frac{1}{2}$ in. apart vertically and 1 in. horizontally. The compartment thus formed between the screens has a free entry to the fish run, so that the young fish nosing their way along the meshes and making for the sea, have every inducement to follow through to the run.

The entrance to the run is controlled by an electrically operated sluice actuated by float gear, so that as the water level is lowered more water is admitted, thus assuring an adequacy of supply at all times. Normally the flow is regulated to 20 million gallons a day but can be regulated according to whether the fish are running or not.

Electric current for the operation of the sluice is provided by a 175 kW generator situated in a compartment built against the downstream side of the dam, the covered tail race leading to the bottom compartment of the fish run, into which it is discharged through a floor grid. This generator is driven by the compensating water necessary to maintain the river flow, which is ordinarily wasted from the power point of view but in this instance it is passed through a Gilkes "Turgo" turbine operating under a head of 45 ft., the current generated being introduced into the 410 volt local network.

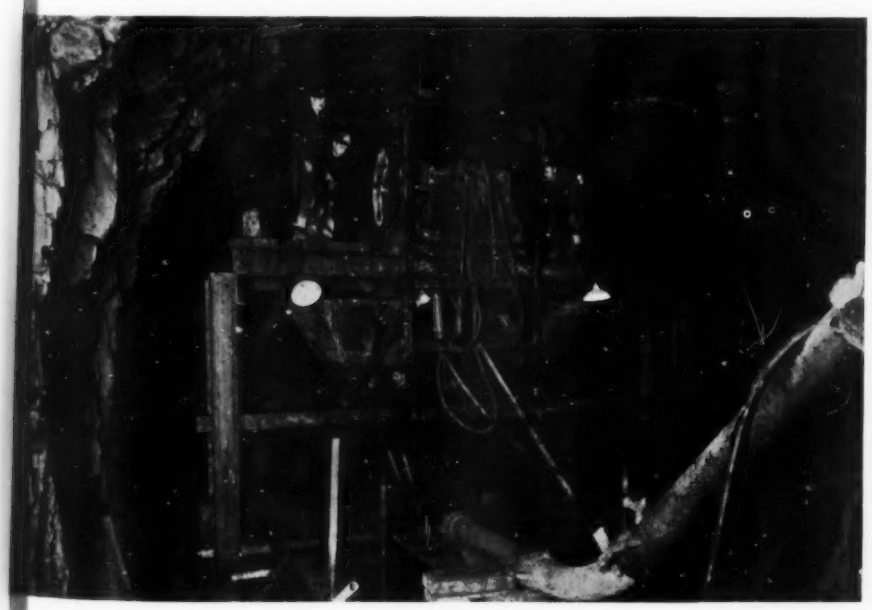
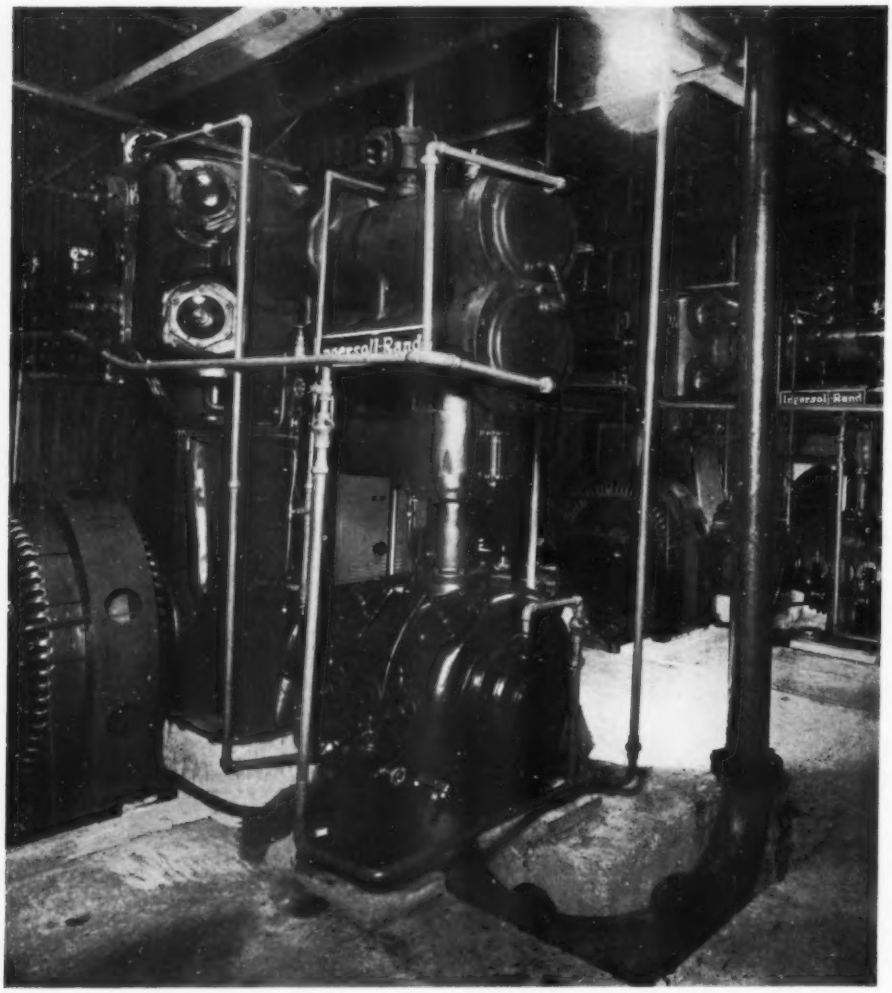


Fig. 14: Concrete gantry showing concrete pumps and pipelines leading to trailing shutter

The Clunie Tunnel

The tunnel connecting the dam to the power station is a stupendous undertaking and is the biggest of its kind in Britain. Some 370,000 tons of rock had to be excavated, for the most part a hard, fine-grained quartzite, although



relatively small amount of seepage which found its way through the rock. For several hundred yards from the intake end the rock is rather weak and is supported by 10 in. by 6 in. section steel arches, over which corrugated steel lagging is laced, the whole being permanently embedded in concrete.

In the unreinforced lining there is a minimum thickness of $7\frac{1}{2}$ in. over the rock points. Generally, however, the thickness is well in excess of this minimum because of overbreakage.

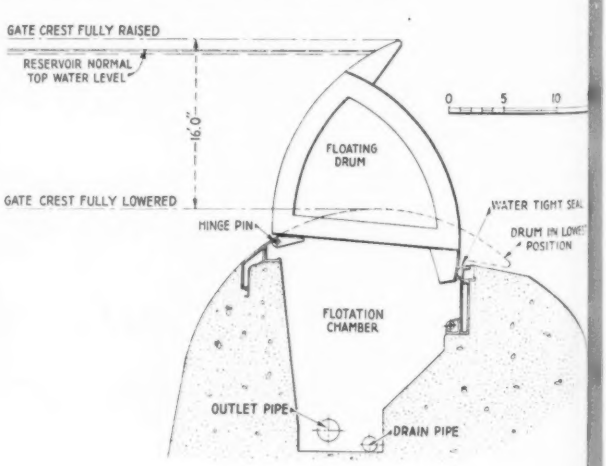
The debris was handled by two No. 21 Eimco rocker-shovel loaders, working in parallel, which discharged into skips of 1-ton capacity. These were moved back a short distance to deliver their load to a shaker feeder which, in turn, discharged the rock to a belt conveyor. The conveyor was extended as the excavation progressed and discharged the rock into one of two elevated bins sited in the open. From the bins compressed air-operated doors gave a controlled flow into tipping wagons of 1 cu. yard capacity, these being formed into rakes for hauling to the spoil dump. Diesel locomotives running on a 2 ft. gauge track were used for this purpose, the intake dump

there were lengthy stretches of micaceous schist; heavy blocks of hornblende were also encountered, 40 to 50 ft. in width, and veins of pure quartz up to 9 ft. in width.

Work proceeded from both ends; initially it was intended to form four working faces by driving an intermediate opening in the mountain side half-way between the extremities, but this idea was abandoned as the time factor rendered it unnecessary and much unprofitable excavation work, duplication of plant and drilling crews was saved by having two working faces only. Pilot headings were driven until the full section of the excavation had proceeded sufficiently far for the drill carriages to be installed. For the remainder of the work the whole section was taken out in one operation, each drill carriage being equipped with 15 Ingersoll Rand pneumatic drilling machines of the heaviest type and furnished with 4-point cruciform bits for the quartzite and 6-point bits for the schist and hornblende.

At the intake end, which is about 50 yards upstream from the dam, the invert of the tunnel is comfortably above the original level of the river bed so that no temporary dam was required, the only water being the

Fig. 15: Part of compressor house showing Ingersoll-Rand units. Fig. 16 (below): Diagram drawing showing typical cross section of drum gate



being piled along the river bank upstream to form a talus below the top water level of the inundation caused by the new dam.

For removing the debris from the outfall-end an inclined shaft, 8 ft. high by 10 ft. wide and 1,100 ft. long, graded at 1 in 3, was driven to the surface. This permitted the spoil to be disposed by piling it high up on the hillside in such a manner as to preserve the amenities. Transport was again effected by belt conveyors; in this instance two temporary storage bins were provided at the open end of the tunnel, the rock being taken thence by trains of side-tipping skips hauled by a diesel locomotive and cast on the hillside.

Also near the outfall is an open surge chamber believed to be the largest of its kind yet constructed. It is excavated in the rock and is 110 ft. wide and 100 ft. deep, being lined with reinforced concrete to a minimum thickness of 18 in., the nominal reinforcements consisting of $\frac{3}{4}$ in. mild-steel bars spaced 18 in. apart both horizontally and vertically. The vertical connections to the tunnel consist of six rectangular openings each 10 ft. by 6 ft. in section and about 9 ft. high. Just before the surge chamber is reached the tunnel section is changed from the horseshoe shape to circular so that the tank is superimposed on the circular section which has a finished diameter of 21 ft. A debris sump 4 ft. deep has been inserted in the floor, slightly downstream of the final vertical opening to the surge chamber, to arrest any particles likely to damage the turbine blading.

The tunnel has a total length of 9,158 ft. and apart from 340 ft. at the outfall and has a horseshoe section equivalent to a circle of 23 ft. diameter, making the

Fig. 17: Hoisting sand and aggregate. Fig. 18: Eimco rock shovels loading tipping cars. Fig. 19: Ingersoll-Rand drifter in operation

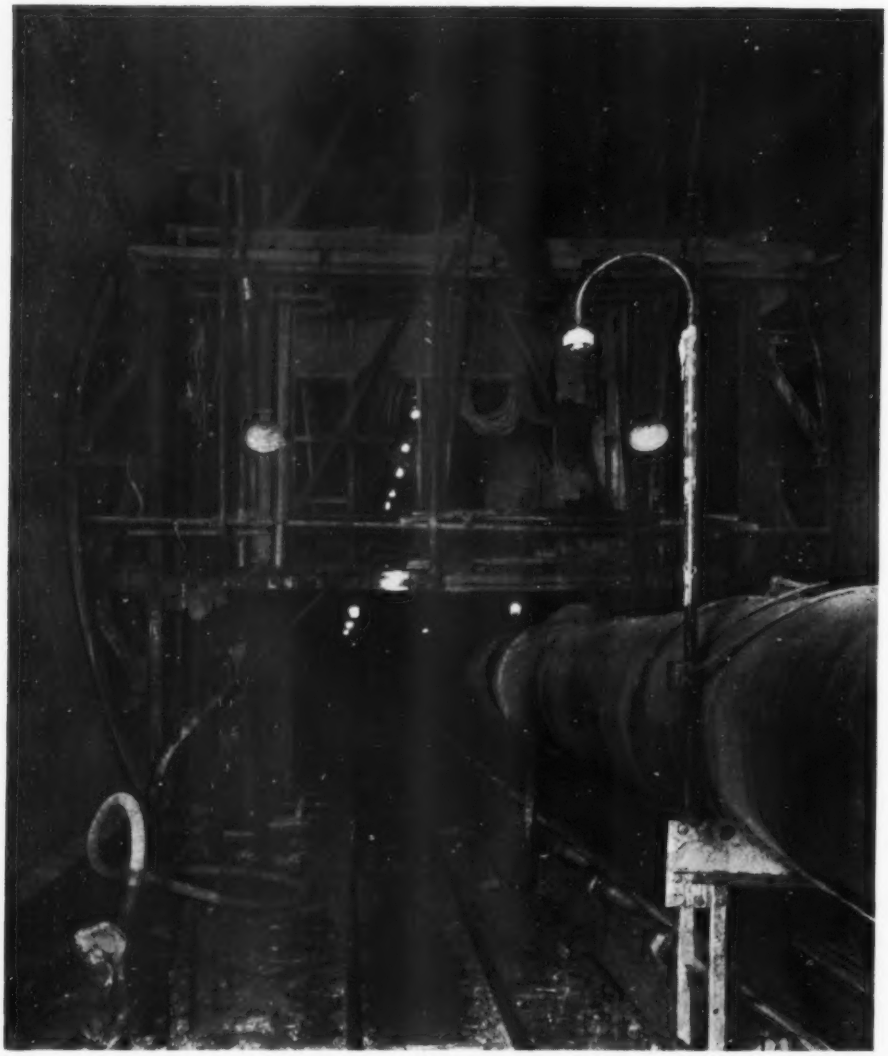


Fig. 20: Finished concrete lining showing travelling shutter

cross-sectional area 416 sq. ft. A final 9 ft. plug of rock separating the two ends was broached by a 700 lb. charge of gelignite on August 30, 1949. At the same time four barrels of beer were broached, one blow-out, as it were, being followed by another, the dynamic by the Bacchic, to celebrate the culminating point of a very remarkable engineering achievement. The centre lines of the two ends coincided exactly for all practical purposes. When operating on full load the tunnel will carry the equivalent of about 2,500 million gallons of water per day (5,000 cusecs.).

For lining the tunnel a travelling shutter was installed 100 ft. long and mounted on four 4-wheeled bogies spaced along the length. In addition to carrying the framework of the structure each alternate bogie unit was provided with four jacks, two disposed horizontally for advancing or retreating the side shutters and two vertically for manipulating the single roof member. For the side member the jacks were of the mechanical type but for the heavier duty imposed by the roof shuttering hydraulic jacks were provided. So that the shutters could be adjusted without fouling each other the side members had a hinging motion which lowered them slightly in an arc as they were retreated and at the same time effected a greater degree of travel at the bottom than at the top. Some idea of the appearance of this structure, which was devised in conjunction with Messrs. C. Parry, can be gathered from the view reproduced in Fig. 20. It runs on rails of 11 ft. gauge and is hauled forward by a power-driven trigger winch.

This device was operated in conjunction with a concrete mixing carriage, likewise 100 ft. long and arranged to travel on the same set of rails. On this three $\frac{1}{2}$ cu. yard mixers were provided, fed from skips and discharging on to an inclined rubber conveyor which raised the concrete to an overhead hopper. From here the mix was discharged into two 6 in. pumps which comprise a hopper charging action combined with a 12 in. delivery stroke. The mix was first poured into the sides, through 6 in. pipes, until the top of the side shuttering was reached after which the crown plates of the top shutter were placed in position and the pipes connected at successive points. A period of 16 hours from the last pour sufficed to harden off the cement before the shuttering was withdrawn. This cycle was maintained regularly. Subsequently the entire arch ring was drilled and grouted at 10 ft. centres throughout the whole distance of the tunnel. The invert was inserted as a final operation using travelling screed profiles.

For the circular portion of the tunnel at the outfall end a separate shutter had, of course, to be used and as curves were involved the concreting had to be done in shorter sections.

The circular section is lined with concrete to within 184 ft. of the outfall after which the lining consists of steel backed by concrete. At the outfall a 21 ft. pipe leads to a trifucation situated in the open and from this three lines of fabricated piping are used to make the connections with the three Francis turbines. There is a taper piece between the 21 ft. diameter welded steel section in the tunnel and the 21 ft. 6 in. riveted pipe in the gun. The piping is constructed of $\frac{3}{4}$ in. steel plates, the interior surfaces having been carefully shot blasted *in situ* and coated with zinc.

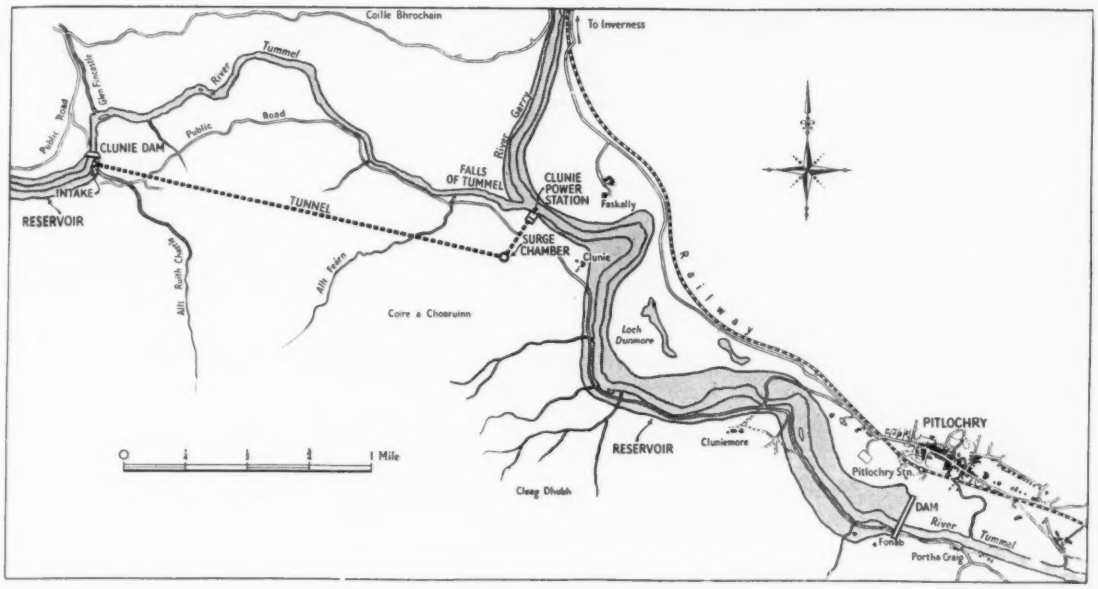


Fig. 21: Site plan showing relation between Clunie and Pitlochry power stations

to a thickness of 0.004 in., by the process developed by Metallisation Limited. Over this protection three coats of bituminous paint were applied. To support the pipes, concrete saddles have been constructed and the whole will finally be encased in concrete and backfilled with soil for amenity reasons. Construction of the draught tubes involved the use of complex shuttering, a separate shutter being required for each tube. The flaring is designed to reduce the tail-race discharge velocity to 7.5 ft. per sec. at full load.

Some information about the power house and the electrical equipment will be given in a subsequent article.

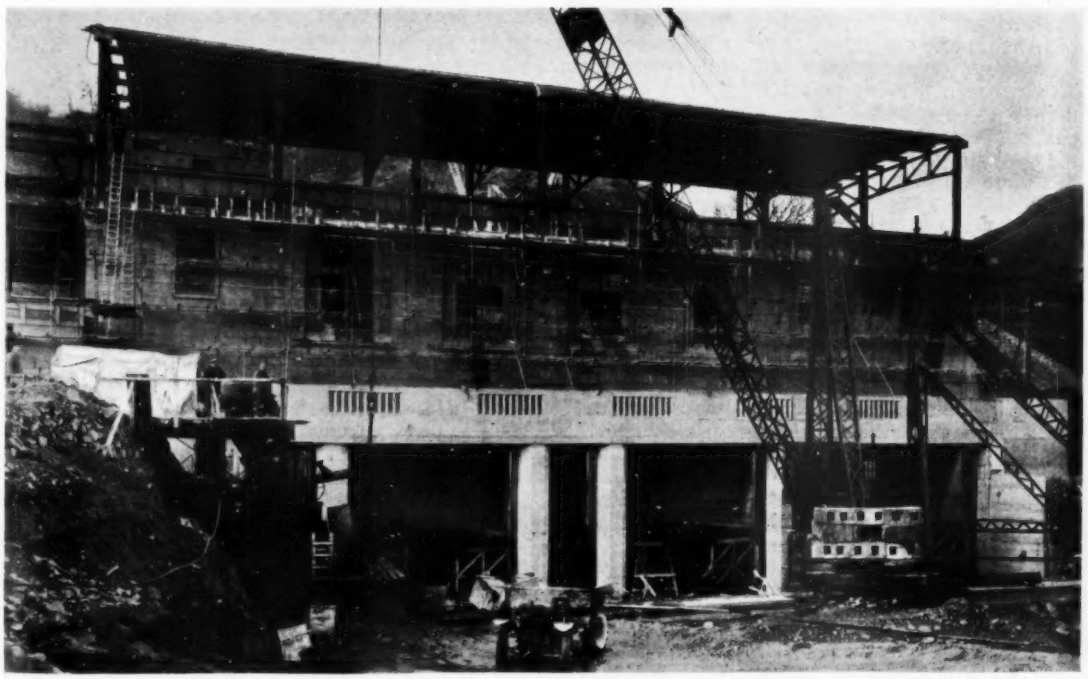


Fig. 22: Clunie power station viewed from tail-race

The Design of Transmission Systems

By W. A. MORGAN, Head, Power System Technical Section, Bureau of Reclamation, Denver, Colorado. A description of the A.C. Network Analyzer, which is used in the planning, design and operation of an extensive electric power system.

Le transport à longue distance vers les centres de consommation est un désavantage dont il faut tenir compte dans l'estimation du coût de la force hydro-électrique. Bien d'autres facteurs doivent aussi entrer en considération: l'analyseur de réseau alternatif, décrit dans cet article, permet de les étudier. Le réseau de force étant représenté sur l'analyseur par ses caractéristiques électriques, on peut rechercher les niveaux de voltage pour toute la gamme de charge, étudier les pertes et choisir les diamètres de conducteur les plus économiques pour les lignes de transport dans la zone desservie.

Generalmente la energía hidro-eléctrica adolece de la desventaja de que tienen que establecerse largas líneas de transmisión hasta los centros de carga y esto es un factor que tiene que ser considerado al calcular el costo de la energía. También tienen que considerarse otros factores, los cuales pueden ser examinados valiéndose del analizador de red de corriente alterna descrito en este artículo. Después de haberse representado el sistema de energía por sus características eléctricas en el analizador, pueden investigarse los valores del voltaje en diferentes secciones para el alcance completo de las condiciones de carga; pueden estudiarse las pérdidas del sistema y pueden escogerse conductores de tamaños económicos para las líneas de transmisión en el territorio de servicio.

THERE are several reasons for the present trend throughout the world towards increasing the development of hydro-electric power. In the United States the multi-purpose projects have emphasized the many benefits that can be associated with hydro-electric power, such as irrigation, flood control, navigation, salinity control, recreation, etc. The irrigation of many thousands of acres of land in the western part of the United States has been made possible because power has helped to pay the cost of the projects; thus new frontiers have been opened, and more work has been provided for an increasing population. The increased cost of fuel for thermal electric power has increased the demand for hydro-electric power—and, of course, the desire to conserve natural resources is an impelling motive for increasing hydro-electric development, especially in those countries where fuel is not plentiful.

However, hydro-electric power usually has the disadvantage of long-distance transmission to the load centres, as compared to thermal electric plants. The cost of long-distance transmission lines enters into the rates that may be charged for the power. Also, the reliability of power transmitted over a long distance may be lowered, depending upon the design of the transmission system. Therefore, a detailed study of the design of the transmission system is essential.

The A.C. Network Analyzer

The best tool now available to the system engineer for the planning, design, and operation of an extensive electric power system is the A.C. Network Analyzer. An electric power system network, including many hundreds of miles of transmission lines, many power plants and load substations, and interconnections with other power systems, may be represented in miniature on the analyzer, which can be installed in a room 25 feet square. Unlike hydraulic models which are made to scale for a given dam or project, the A.C. Network Analyzer has adjustable units so that the load, voltage, impedance, or other parameters of the power system may be adjusted at will so that any number of system conditions can be studied. Figure 1 shows a picture of the Bureau of Reclamation's A.C. Network Analyzer in use during the adjustment stage of a study.

Once the power system has been represented by its electrical characteristics on the analyzer, the voltage level at various buses can be investigated for the full range of load conditions to be expected, and the range of fixed transformer taps, tap-changing-under-load voltage regulators, or need for reactive power equipment, determined. The system losses can be studied and economic conductor sizes selected for the transmission lines. The generator characteristics may be determined and, by scrutinizing the flow of power over the system, the best voltage and arrangement of the transmission system decided upon.

Long-hand calculation methods are laborious, time consuming, limited in scope, and break down almost impossible on complex power systems. The result has been that in the past we have relied considerably on engineering "judgment" based on past experience, and the use of trial and error methods. Sometimes the errors and limitations in system design have been costly to correct.

Now, the A.C. Network Analyzer gives us facts and figures upon which to base our decisions. In addition, it allows us to look to new horizons in considering new types of power system equipment that heretofore have not been used. The effect of faster circuit-breakers and relaying, circuit-breakers

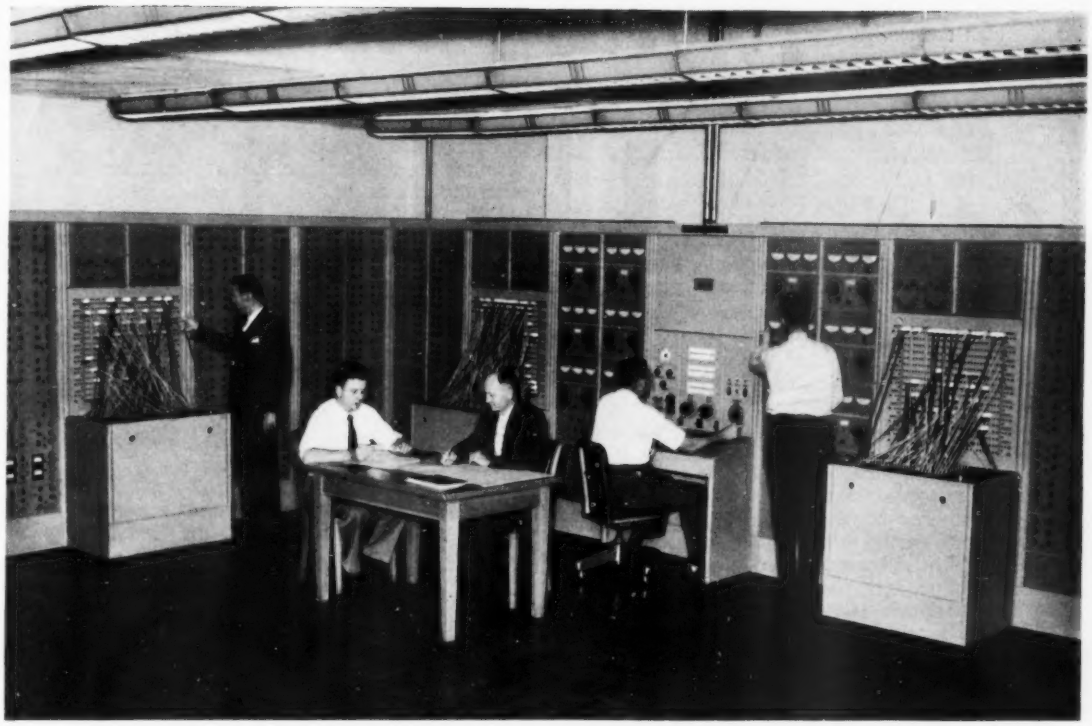


Fig. 1: General view of A.C. Network Analyzer of the Bureau of Reclamation, Denver, Colorado. The analyzer is shown with an extensive power system "plugged" up for a study. The analyzer has 108 line units, 42 capacitor units, 32 adjustable voltage load units, 12 generator units, 12 synchronous impedance units, 18 auto-transformer units, 12 mutual-reactance transformer units, and 4 large capacitor units

which reclose in one-third of a second, series capacitors in the transmission line to reduce the line impedance, duplex conductors, or transmission voltages higher than now used, may all be studied and their effect determined before any money is spent on the power system equipment. In this manner, the transmission systems of the future may be less costly and more reliable, and these are important factors in hydro-electric power system design.

Figure 2 is an example of how the A.C. Network

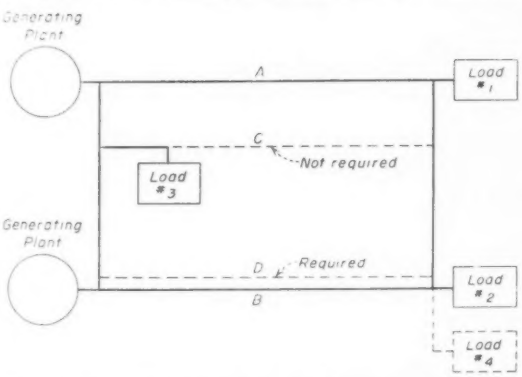


Fig. 2: The network analyzer reduces guesswork to a minimum. Line "D" is required to serve new Load 4, even though Line "C" would require a shorter new section of line because of existing line already serving Load 3

Analyzer aids in the layout arrangement of a power system from a steady-state performance standpoint. In the figure, Loads 1 and 2 are supplied over Lines "A" and "B" from two generating plants, and Load 3 is served by a line that extends part of the way on the "C" route. The transmission system is arranged in a loop. It was natural for the operating engineer to suggest that a new line to supply the increased requirements brought about by new Load 4 could be accomplished by extending the line over the "C" route. Such a line would be shorter and, at first glance, would appear to be the least costly scheme. However, in this case, the analyzer showed that Line "C" would not carry its share of the power because of the location of the new load and the impedances in the network. In other words, such a system would have higher losses, would have poor voltage regulation, and the improvement for the money expended would be low. The construction of Line "D," instead of Line "C," would give a better proportionate loading of the lines, would have lower losses and higher efficiency, better voltage regulation, and would be lower in overall costs. Thus, the analyzer showed how to get the best results from the system for the money to be expended.

Figure 3 illustrates the savings that might be accomplished by the use of the A.C. Network Analyzer in transient stability problems. In a particular example, regular design practices would have made it reasonable to assume that three 230-kV circuits would be required to transmit the output of a pro-

posed large generating plant to the various potential loads which are shown as a composite in the figure. However, the analyzer was used to determine the

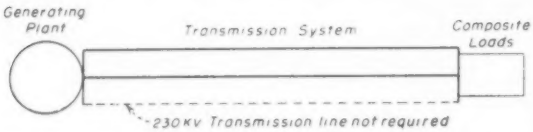


Fig. 3: Major savings in transmission system design costs can be realized because the margins may be accurately determined and the factors of safety kept with known limits

effect of generator characteristics, faster oil circuit-breakers and relays, and fast reclosing circuit-breakers on the design of the transmission system. Although all the details are not presented, the result showed that by specifying lower-than-normal generator reactance, which would increase the cost of the generators a certain amount, one of the three 230-kV transmission lines could be eliminated. The saving in eliminating the transmission line would be many times the additional cost of special generator characteristics, so a net saving in overall power system costs may be very considerable.

Stability of a Power System

Some perception of " stability " of a power system can be gained by the general engineer in referring to Figure 4, which is a mechanical simile of a long transmission line with synchronous machines at each end. We know that in the mechanical simile an increase in weight stretches the spring and increases the angle between the two levers. Thus, we establish the axiom that the mechanical system is stable so

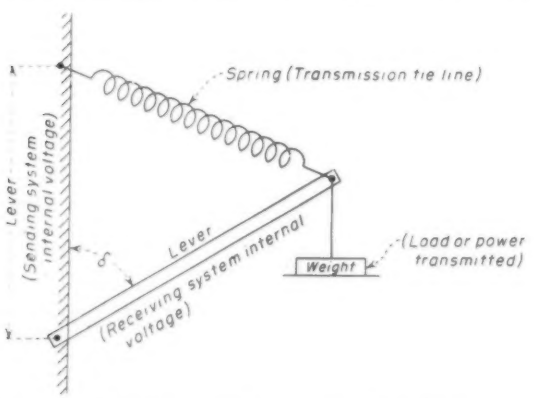


Fig. 4: Mechanical simile of a long transmission line connecting two synchronous machines or two large parts of the power system together

long as an increase in angle corresponds to an increase in weight. We know that the mechanical simile will not be stable when the angle has been increased by the weight above approximately 100 degrees. A critical angle will be reached where further increase in angle will not support additional weight and the mechanical system is unstable. Substantially the same effect is found in the electric power system, where the transmission line characteristics are represented by the spring, the weight by the power transmitted over the transmission line, and the two levers correspond to the voltages in the synchronous machines at the two terminals of the line. The electrical system is stable so long as an increase in angle results in an increase in power transmitted. If the critical angle is exceeded, the system becomes unstable, the synchronous machines run out of synchronism with each other, and interruption to the service results.

Described briefly above is what is termed " steady-state " stability of a transmission system, where the load has been increased slowly until instability is reached. Transient stability is somewhat analogous, although it is complicated by consideration of the inertia of the synchronous machines as they oscillate electrically with respect to each other. The A.C. Network Analyzer makes possible the study of transient stability conditions as well as steady-state performance of any power sytem.

Figures 5(a) and 5(b) show the " power-swing " curves which resulted from such a transient stability analyzer study. In each the ordinates correspond to the relative displacement in electrical degrees between the generators or power plants on the system; or, to refer back to Figure 4, the ordinates show the "angle" between synchronous machines. The *abscissa* shows the time in cycles on a 60-cycles-per-second base after a lightning stroke caused a flashover fault on one of the lines. In this case the relay and breaker inter-

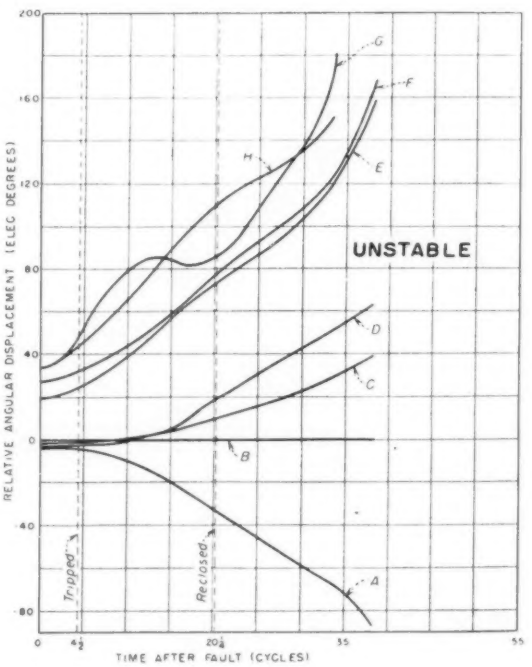


Fig. 5

Figs. 5 and 5a: Power-swing curves resulting from an A.C. Network Analyzer study of transient stability of a power system. The curves result from points calculated at 2- to 4-cycle intervals (60-cycles-per-second base) which consider the inertia constant for each machine in a step-by-step procedure. Each machine angle point determines a new machine output (kW) which is measured by instruments, and this new out-

put determines the next angle position of the machine which is set by the operator before the next set of readings is taken. The three-phase fault was assumed cleared by the circuit breakers at both terminals of the line in 4-1/2 cycles by means of carrier relaying. (a) shows the power-swing curves for an "unstable" fault condition. (b) shows that special generator characteristics can make the system "stable" for the same fault and loading condition as for (a)

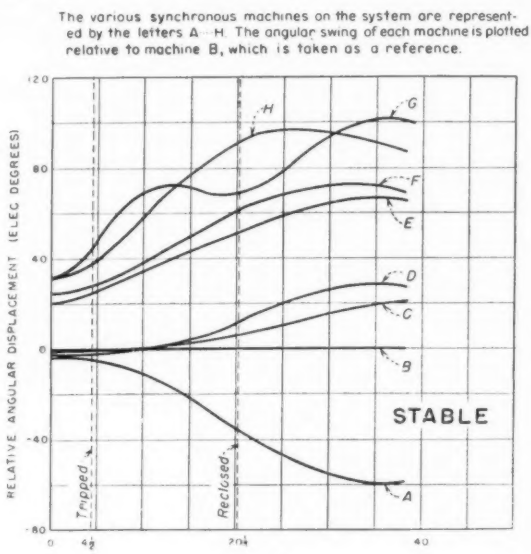


Fig. 5a

rupting time was assumed to be 4.5 cycles which is conservative. Subsequent studies assumed 4 cycles, which is more generally accepted. Also, the reclosing time for the breakers in the figure was taken as 20-1/4 cycles, whereas reclosing time down to under 12 cycles is obtainable with modern carrier current relaying and oil circuit breakers, although the safe lower limit has not yet been determined from the standpoint of the fault arc re-establishing itself through the deionized air when the line is re-energized.

Figure 5(a) shows that the power system would be unstable for a given loading condition and fault location with normal calculated value of generator transient reactance. This is readily observed because the angle in electrical degrees between some of the synchronous machines has gone beyond the critical point at an increasing rate.

Figure 5(b) illustrates the effect of special generator characteristics. The loading and fault conditions were identical with those of Figure 5(a). The only difference was that the generator transient reactance was lowered to 85 per cent. of normal calculated value. In this case the power system is stable. The synchronous machines swing away from each other initially, but the swing is within the critical angle for this system and the synchronous machines pull back together after the breakers have closed to re-energize the previously faulty line. The study was not continued after it was found that the generators were pulling back together, although if it had been it would be found that the generators would find their pre-fault relative positions after oscillating back and forth a little.

The transmission of electric power over long distances is a problem directly associated with hydro-electric developments. The long distance increases the length of the spring of the mechanical simile shown in Figure 4 and makes the system operate closer to the critical angle. Thus the problem in the a.c. power system is to overcome, electrically, the physical long distance and reduce the angle between synchronous machines. This is an immediate problem because the favourable hydro-electric power sites close to the loads have already been developed, and the available sites are located at increasingly greater distances from the loads.

High-voltage d.c. transmission has been proposed as a way to overcome the stability limits of a.c. systems for long lines. Considerable research and experimental work has brought to light several major limitations with high-voltage d.c. transmission which makes its use doubtful in the near future. The lack of adequate high-voltage breakers for direct current would limit d.c. transmission to two terminal systems. The rectification system itself is still subject to transient disturbances which appear to be less understood or controllable than the stability problem of an a.c. power system. Thus, the power engineer may still consider only alternating current for long-distance transmission of electric power at the present time.

The stability limit of a long a.c. transmission system can be increased in several ways, all of which are being put into practice throughout the world to-day. Increasing the transmission voltage is the most effective manner of improving the power limit of a line. Table 1 shows how the surge impedance loading

TABLE 1
Transmission Line Characteristics

KV Rating of Transmission Line	Unity PF or Surge Impedance Loading of Line —MW	Charging kVA per 100 miles of line—MVAR
115	33	7
138	48	10
161	65	14
230	132	28

capacity and the light-load charging kVA requirement of a line are increased by raising the voltage. Surge impedance loading occurs when the charging kVA due to capacitance of the circuit is balanced by the inductive reactance kVA of the current, so that the line itself operates at approximately unity power factor. The lines usually are able to carry more than surge impedance loading, depending upon line length and arrangement of system at the terminals; however, the relative surge impedance loadings for the different voltages are a rough comparison of the relative capacities of the different voltage lines.

Examination of the surge impedance loadings for the different voltages in this respect shows that the power limit of the transmission line varies approximately as the square of the voltage. In its simplest application, a 230 kV system would have almost four times the stability limit of a 115 kV system, depending upon the other factors affecting the limit. The cost of a higher voltage transmission system goes up in some proportion to the voltage, and only systems to be used for transmitting large quantities of power can justify the higher voltage lines. The 287 kV system

in the United States is the highest transmission voltage in use, although 380 kV lines are now planned or being built in Sweden, France, Switzerland and the United States. The choice of voltage should be based upon the comparative costs of a large number of lower voltage transmission lines and a small number of higher voltage lines for a given block of power to be transmitted. Other factors to be considered, of course, are interconnections with other power systems, right-of-way problems, and arrangement of the power system. For example, it might be better from the standpoint of system performance, maintenance, and service reliability to have two 161 kV lines than only one 230 kV line.

Another way to increase the power limit of a line is by means of series capacitors inserted in the transmission line to offset the inductive reactance of the line. In Figure 6 it is shown that, for the same amount of power transmitted, the transmission line with the

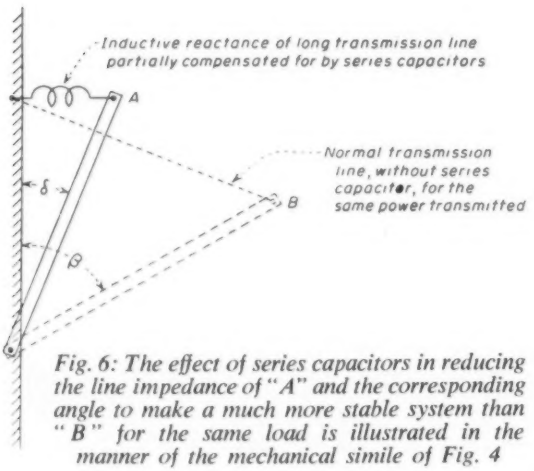

Inductive reactance of long transmission line partially compensated for by series capacitors
A
Normal transmission line, without series capacitor, for the same power transmitted
B
δ
θ

Fig. 6: The effect of series capacitors in reducing the line impedance of "A" and the corresponding angle to make a much more stable system than "B" for the same load is illustrated in the manner of the mechanical simile of Fig. 4

series capacitors would be more stable than the line without them, because the angle between the synchronous machines is less. Or, conversely, for the same angle and margin of stability, the power limit of the line with series capacitors would be higher. Theoretically, the inductive reactance of the transmission line could be completely compensated by the series capacitors. Practically, there are voltage, switching, and relaying problems to be overcome in the use of series capacitors in high-voltage lines. Two installations for 230 kV lines are to be made soon in the United States and it is expected that the studies, tests, and experience on these installations will lead to satisfactory solutions to the new problems. Series capacitors are being installed on 230 kV lines in Sweden also. There are already in the United States several installations of series capacitors at 33 kV and 66 kV which have operated satisfactorily for several years. The relaying problem for series capacitors on long high-voltage lines protected by instantaneous directional distance or impedance relays may be overcome if the capacitors could be installed in the middle of the line and limited in capacity to 40 or 45 per cent. line compensation. Under these conditions correct directional operation of relays would be assured for all line faults, either before or after the series capacitors are shorted out by their protective switches. However, in some cases it may be desirable to locate the series capacitors at the terminals of the line for maintenance purposes, or to use a line compensation of greater magnitude than 45 per cent., and modifications to our present protective relaying schemes will be necessary when this is done.

The use of duplex conductors is another way of increasing the power limit of a transmission line. However, the reduction in transmission line inductive reactance by this method is limited to about 20 per cent. and so duplex conductors do not have the possibilities that series capacitors have in transmission line compensation. Duplex conductors consist of spacing two conductors about 18 inches apart for each phase, and the lower reactance of this scheme was emphasized when duplex conductors as a solution to the corona problem were proposed for 380 kV transmission lines. It is understood that duplex conductors are being installed on some existing 230 kV transmission lines in Sweden to increase the current carrying capacity as well as the power limit of that system until the 380 kV system is completed; but no installations are known to be contemplated in the United States.

The interconnection of power systems is one of the most stabilizing factors that can be accomplished in a power system and increases the power limits of all the parts of the system. The inertia of the inter-connected system is much larger than for the individual parts of the system which make it up, and a loss of a specific load has less tendency to increase the speed of the system and cause instability. Of course, there are other mutual benefits such as interchange between systems during emergencies so that less standby equipment by each individual part may be maintained when the systems are interconnected. Interconnections mean that the loading of the transmission lines can be greater on the power system. An increase in size of the conductors used for the transmission lines might be economically justified in a system that was likely to carry heavier loads because of interconnections, but not if an isolated system was first contemplated. In the United States it has not been possible as yet to interconnect all the power systems because of the long distances involved, an area of approximately 3,000 miles east to west by approximately 1,200 miles north to south. However, the Northwest Power Pool, to which Grand Coulee Power Plant is connected, now extends about 800 miles east to Fort Peck Power Plant in Montana and soon will extend 300—400 miles further east when lines into North Dakota are completed. Another interconnection which includes the Tennessee Valley Authority Power System extends from Georgia to Nebraska. It has been electrically possible to interconnect the Pacific Coast Power Systems from Canada into Mexico, over 1,200 miles. Therefore it is not inconceivable that the power systems of the United States will all be completely interconnected in the not too distant future.

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The Ybbs-Persenbeug Scheme

A comment by Dr. CHAS. JAEGER, on the Danubian low-head project described in detail by Professor Grzywienski[1]

ALL engineers connected with the design of low-head hydro-electric schemes will read with interest the detailed account by Prof. Grzywienski of his project for the Danube Scheme at Ybbs-Persenbeug.

A powerhouse containing eight 26,300 h.p. turbines —a total of 210,400 h.p.—is projected, the output of the station varying from 60,000 kW at low water (640 m³/sec.) to 150,000 kW, corresponding to a river discharge of 2,000 m³/sec. The average output, it is estimated, will be 115,000 kW, yielding approximately 1,000 million kWh per year.

The author describes several older projects, the first dating back to 1924, with headrace and tailrace canals. The basic scheme is one presented in 1922 by Mr. Oskar Höhn and sponsored in 1938 by the Rhein-Main Donau A.G. (Prof. Dantscher). This consisted of a weir and powerhouse built in line across the river, a conventional design essentially similar to the more recent project described by Prof. Grzywienski.

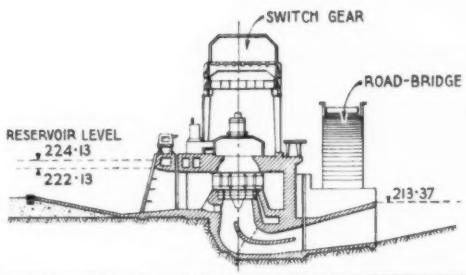
In the period between these two schemes, Arno Fischer developed an underwater powerhouse design for Ybbs-Persenbeug, similar to the much smaller stations which he built during the war, in South Germany. The most important features of the underwater power-house are the axial flow turbine, arranged on an inclined axis, and the generator placed co-axial with, and in the same radial plane as, the turbine. Site work was actually commenced on this design.

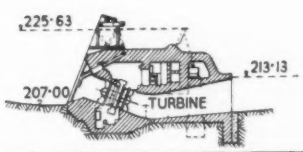
In 1945, the Alpen Elektrowerke A.G. submitted the so-called " Pfeiler Kraftwerk " (pier powerhouse), a new design, which this company had already developed for some smaller power stations. In this type of construction, the turbines are individually located in the piers of the weir, which are specially enlarged for the purpose. Each pier is thus developed as a powerhouse, with intake and spiral casing, the turbine axis being vertical .

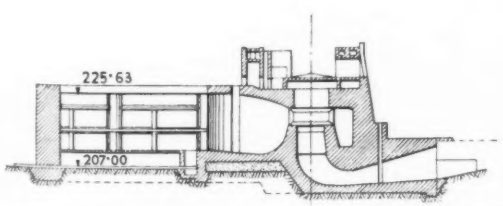
It is interesting to note that Prof. Grzywienski, who had the opportunity of studying both these latter designs in detail, now proposes reverting to the more conventional scheme, which he presents as the official project.

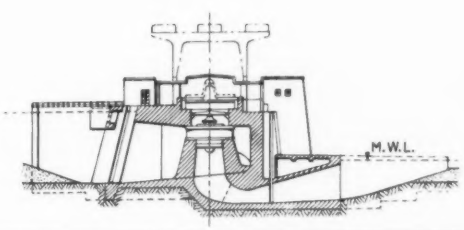
There are many differences between the Höhn project (1922) and the Grzywienski scheme (1946-1947). In the more recent project the headrace water level has been fixed at 225.63m O.D. as against 224.13m O.D. in the Höhn project. The main difference lies in the general arrangement in plan. The forebay protecting the powerhouse in the Höhn project, has been omitted from the modern project, an evolution similar to that of the power stations on the Rhine. The arrangement proposed by Höhn is reminiscent of Laufenburg on the Rhine (or even more so of Chancy-Pougny on the Rhône); the arrangement proposed by Prof. Grzywienski is of the type of Ryburg-Schwörstadt on the Rhine, or better still, of the T.V.A. low head power stations.

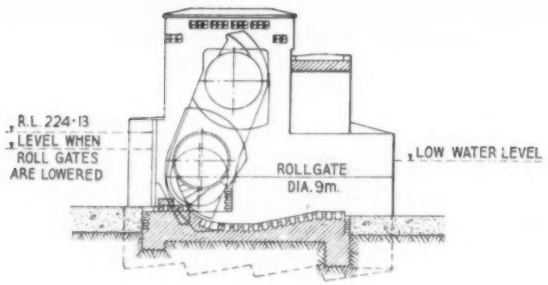
Characteristic of the whole project of Prof. Grzywienski is the fact that the powerhouse is of the free air type. The same gantry crane services the weir, the power house and also the downstream lock gates.

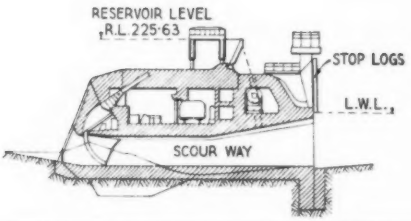


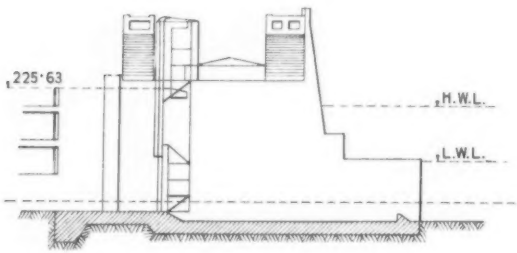


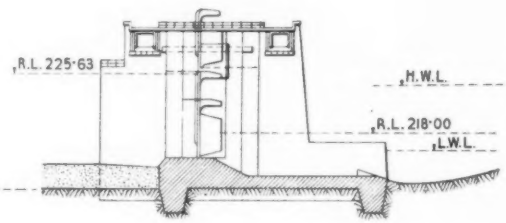


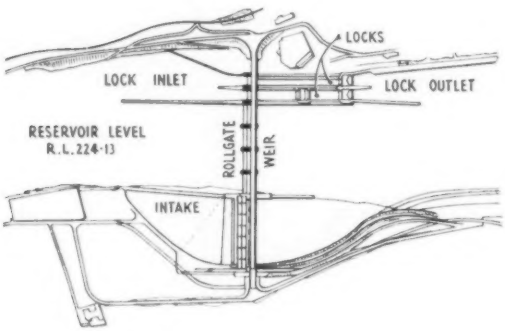


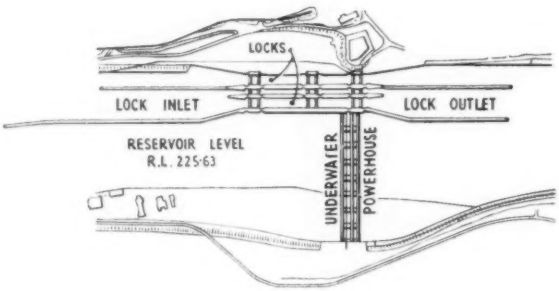


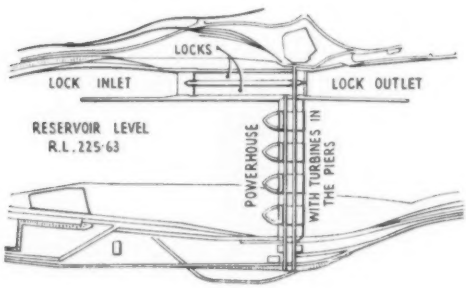


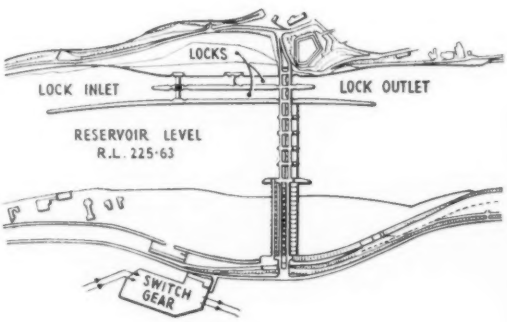












This important evolution in modern power plant, initiated in Sweden (Vargon Powerhouse), was developed in the U.S.A. to become a standard design. Two bridges run from one end of the station to the other at elevation 233.00m. The weir is equipped with hook gates, similar to those of Ryburg-Schwörstadt, but far larger. The gate width is 30m and the water pressure may exceed 15m (dimensions of Ryburg-Schwörstadt: 24,00 × 12.00m).

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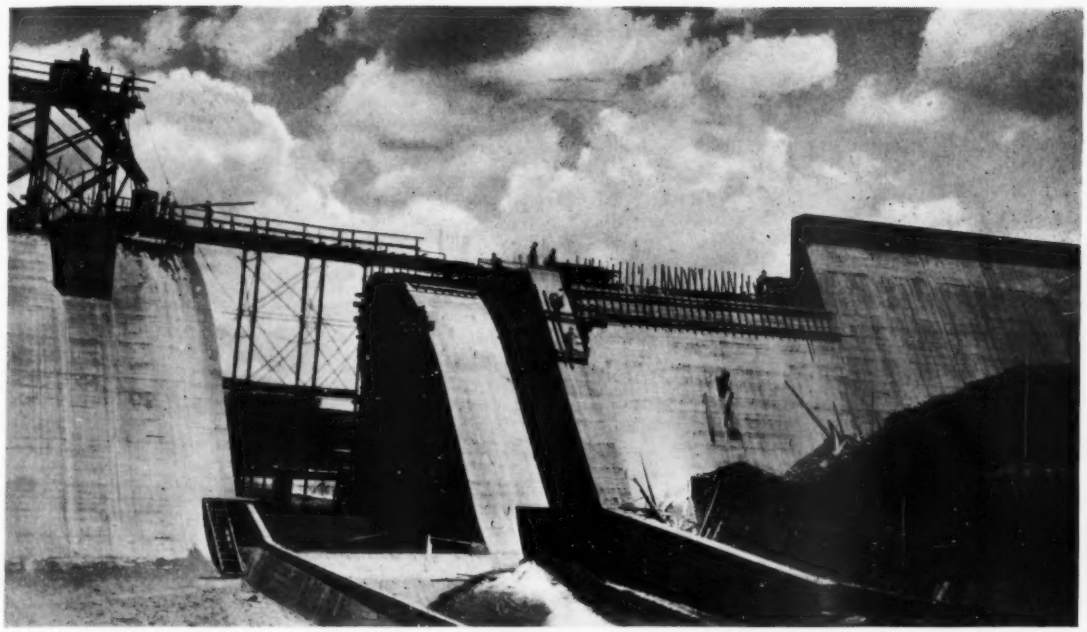


Hydro-Electric Expansion in Brazil

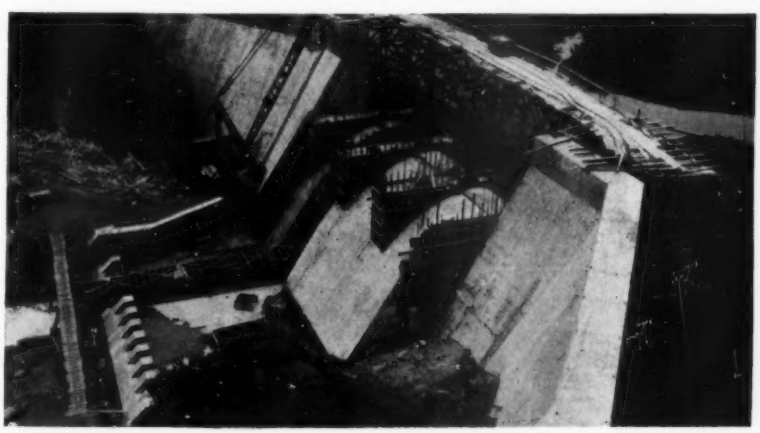
An extract from an interview with Mr. Elmer F. Johnson, president of the *Companhias Auxiliar de Empresas Eletricas Brasileiras*

THE American and foreign power subsidiary company operating in Brazil under the name of *Companhia Auxiliar de Empresas Elétricas Brasileiras* started work in 1927. To-day the 19 serving companies—virtually all of which are managed by Brazilians, with 97 per cent. of the more than 15,000 employees also Brazilians—supply 334 communities, including the capitals of ten States, totalling something like six million people.

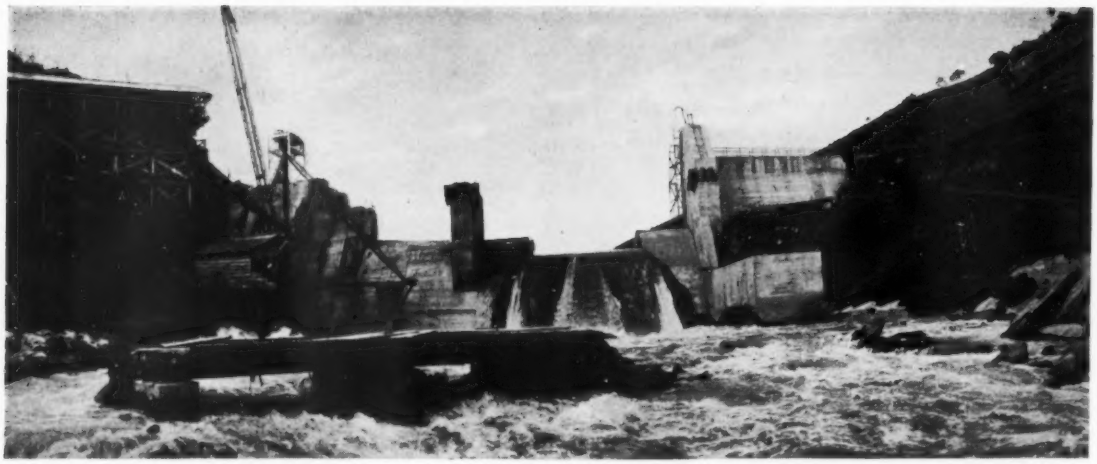
On a post-war expansion basis the companies at the close of 1949 will have an installed generating capacity of 344,038 horse-power, compared with 216,866 horse-power as of the end of 1944. Looking beyond 1949 there are plans for raising generating capacity by 158,238 horse-power — provided the necessary financing is arranged.

Four major projects are scheduled to come into operation now, or in the near future. They include the Avanhandava hydro-electric plant situated near the city of Peneapolis, State of São Paulo—Brazil's most progressive State—which involved the installation of a third unit of 13,410 h.p., bringing the capacity of this plant to 40,230 horse-power. Avanhandava is the most modern hydro-electric plant in South America and the largest in the hinterland of Brazil.

The Americana plant 60 miles north-west of the city of São Paulo — installation of the first two units with a combined horse-power of 26,820, which



Top: Americana hydro-electric station, State of São Paulo
Right: Vossoióca dam of the Chamisé power plant



ultimately will be brought up to a total of 40,230 horse-power.

The Areal station, 30 miles north-west of the city of Petropolis, in the State of Rio de Janeiro—installation of the first two units with a combined capacity of 24,138 horse-power. This plant will serve Niteroi, the State capital, and Petropolis, Brazil's summer capital.

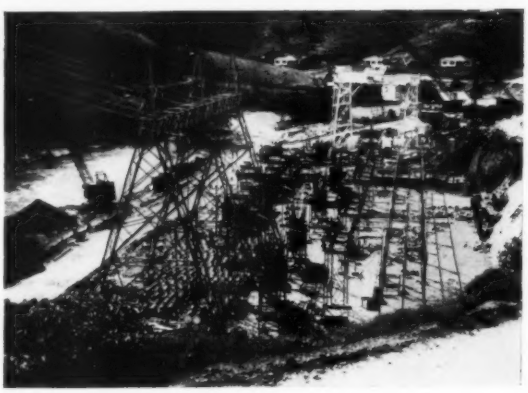
The fourth is Vossoróca storage dam, in the State of Paraná. The project will increase the facilities of the Chaminé hydro-electric plant which supplies the capital city of Curitiba. The reservoir will increase the capacity of the present three-unit plant (in dry weather) from 10,460 horse-power to 17,165 h.p., and also will permit the installation of a fourth unit of 5,364 horse-power in the Chaminé plant.

These four projects will represent a total expenditure of U.S.$22,600,000; more than U.S.$4,500,000 was spent in 1949 to bring them to completion, not including further substantial outlays for minor expansions which were carried out on the properties last year.

Two new projects are being considered — the Marimbondo, which is planned for northern São Paulo on the Rio Grande, initially with two units having a combined capacity of 53,640 horse-power, with an ultimate generating capacity of 187,740 horse-power. The other project is on the Rio Paraopeba, near the town of Florestal, in the State of Minas Gerais, with an initial capacity of 33,525 h.p. which will supply Belo Horizonte, the State's capital, with electricity.

The company expects to finance these projects with the assistance of the Export-Import Bank of Washington. It is also hoped that Brazilian investors will raise additional capital by selling securities of the Brazilian companies involved, in furtherance of the company's policy of affording the Brazilian public an opportunity to participate in the ownership and management of these companies.

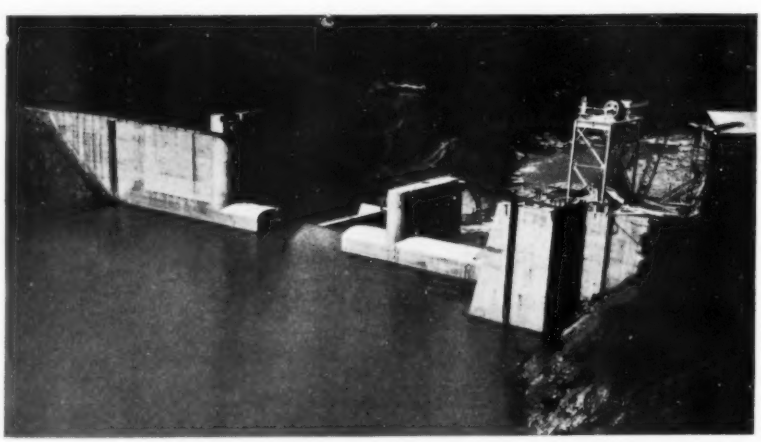
E. A. Borges.



Top: Areal dam in course of construction

Above: Sub-station at Areal

Below: Upstream view of Areal dam and station, in the State of Rio de Janiero



Book Reviews

Technische Hydraulik

By Dr. Charles Jaeger; published by Verlag Birkhauser, Basel, 1949. The appearance of the first text book by this well known Swiss engineer will arouse considerable interest amongst hydraulic engineers all over the world. Although the title "Technical Hydraulics" is quite general, the book is really a specialized work on several important aspects of hydraulic engineering upon which the author is an acknowledged expert.

The four main sections of the book have general titles:

A. Physical basis of hydraulics;
B. Steady flow (open channels);
C. Unsteady flow (surges oscillations, waves and water hammer);
D. Ground water flow;

and there are two appendices, the first on empirical design data for hydraulic calculations and the second on the flow in open channels with loose beds. The book is clearly printed and well illustrated with sketches and diagrams, and is the eighth of the publisher's series of engineering text books.

One of the first things which strikes the reader is the abundance of references and brief biographical notes on all the classical hydraulicians quoted, which, as well as being most interesting, show the enthusiasm of the author for his subject.

Section A contains no new material but reviews the growth of fluid mechanics, boundary layer theory and fluid resistance laws, leading up to an account of pipe-flow theory and losses in smooth and rough pipes. Perhaps its main value for engineers outside the continent is the table of pipe friction coefficients recommended by the Swiss and Italian schools.

Section B is the most complete work on flow in open channels since Bakhmeteff's book. Part 1 is devoted to the general equations of motion, Bernouilli's theorem applied to flow with a free surface, and the momentum equation is then used to illustrate various simple cases such as losses at transitions, jet reactions and forces on bends. In Part 2 of Section B the theorem of Belanger is illustrated for flow with a free surface and the close relationship of the flow, momentum and energy equations is emphasised. This aspect has been described in English by the author in the journal of the Institution of Civil Engineers. Part 3 covers the calculation of surface profiles with and without discontinuities and derives the normal backwater and drawdown curves for many practical cases of flow in prismatic section channels, overfalls, steps, contractions, expansions and shapes of spillways and buckets for dams.

Section C is the most comprehensive work on pressure surges, waves and water hammer that has yet appeared in text book form, and is a subject upon which the author is an acknowledged expert. He uses material from some of his previous papers and he also covers more recent developments. Part 1 derives the elementary oscillation equation and draws from Calame and Gaden, Prasil, and others in demonstrating their solution by direct and step by step integration. The oscillations of tunnels and then surge chambers are described and the equations put into coefficient form for convenience. The stability of surge tanks is then considered and the graphical methods of Frank, Calame and Gaden, Shoklitsch and others are described for finding the various damping and stability factors. Several types of differential surge chamber and branched pipe system are included and the equations derived for most main types of problem encountered in hydro-electric schemes. Part 2 covers water hammer and draws from the classical work of Allievi and many of the author's previous papers. Pressure surges in branched and tapered pipes are considered and then the equations for systems complete with surge tanks and regulated turbines are included. The graphical methods of Schnyder and Bergeron are described and their use advocated. In Part 3 the surge problem is applied to waves in canals and free surface tunnels. The classical work of Boussinesq and St. Venant are described and the more recent work of H. Favre quoted together with numerical and graphical methods of solution.

The whole of Section C is a magnificent review of unsteady flow problems which confront the hydro-electric engineer and the many methods by which solutions may be obtained.

Section D deals with the flow of ground water in porous media and draws from the works of Dupuit, Kozeny and Forscheimer, pointing out the inaccuracies in the various methods and introducing modifications and improvements evolved by the author.

Appendix 1 gives design data for pipe and mitre bed loss coefficients and energy losses in branches, trashracks, and finishes by describing standard methods of flow measurement. Appendix 2 summarise the work of Casey, Indri, Conti, Shields, Hunter Rouse, White, Einstein and Muller on the flow of water in channels with loose beds. Empirical rules are given for predicting bed movement, ripple-formation and scour. This is a useful collection of data that so far has only appeared in technical reports and gives valuable data for estimating the depth of erosion under sluices.

This text book is written by an expert who has the advantage of great practical experience backed by a fine theoretical knowledge of his subjects. Dr. Jaeger is much more in touch with American and British work than most continental authors and has drawn widely from an international field. It is highly specialised and is not recommended for elementary students; but the book is likely to be used as an advanced work of reference for many years and will rank high in contemporary hydraulic literature.

Unfortunately only those engineers reading German will be able to appreciate *Technische Hydraulik* at the moment, but it is to be hoped that this important work will be translated into English as soon as possible.

S.P.H.

Applied Hydrology

By Ray K. Linsley (Jnr.), Max A. Kohler and Joseph L. H. Paulhus. Published by McGraw-Hill Publishing Company, 1949. 9 in. x 6 in., 689 pp. Illus. Price 72s. 6d. All three authors of this book are officials of the United States Weather Bureau, and the fact that the results of their work have been published by a commercial firm reflects the extra-

ordinary freedom in which technology operates in America.

The emphasis throughout is on the practical application, the vast data that have been accumulated being presented in a form to subserve this end. Consequently the book provides the practising technologist with a convenient source of reference on all hydrological matters and should be of immeasurable help to students in mastering theoretical considerations and the practical issues which devolve on them. Highly specialised and unusual applications have not been included, the authors being content to give an adequate bibliography and to concentrate on the more generally applicable techniques.

The scope is extensive as may be gathered from the chapter headings—climate, temperature in the atmosphere, atmospheric humidity, winds, precipitation, snow and frost, evaporation and transpiration, streamflow, drainage pattern of the basin, surface retention and overland flow, soil physics, sedimentation, ground water hydrograph analysis, run-off relations, run-off distribution, waves, flow routing and gauging, design and operation of water-control works, and river forecasting. Appendices deal with graphical correlation, sources of data, and physical constants and conversion tables.

It should be understood that the basic data used in this book are all referable to the United States, excepting a few instances where non-American data have been introduced to illustrate some point; but the breadth of treatment and adherence to fundamental principles give this work a value in any country where applied hydrology is of economic importance.

Electrical Engineer's Reference Book

General Editor: E. Molloy. Published by George Newnes Ltd., London, price 50s. This excellent compendium of knowledge now appears in its fourth edition. As one who has spent much time in electrical libraries, the reviewer declares it to be the best publication of its kind in the English language.

Hydro-electric engineers in the past might have complained that previous editions did not contain more than a passing reference to their own subject. This has been rectified in the present edition and an eight-page section, under the general heading of "Power Station Practice" is devoted to a review of present-day hydro-electric developments and practice.

Another new feature deals with hydrogen-cooled alternators (which are used principally in thermal stations), and there is much fresh information about wiring, contracting, and fluorescent lamp data. All the sections of the book have been revised to bring them in line with recent developments.

Hydraulics and the Mechanics of Fluids

By E. H. Lewitt, B.Sc., Ph.D., M.Inst.Aero.E., A.M.I.Mech.E. Published by Sir Isaac Pitman & Sons Limited, London, 1949. 8¾ in. x 5½ in., 625 pp., 285 ff. Price 21s. That this book should now have achieved eight editions is evidence enough of its continued popularity with successive generations of students, and we find this in no way surprising. Its value lies in the clarity and directness with which the author deals with his subject and the fact that he never loses sight of first principles. The numerous examples and the discretion which has obviously been exercised in their selection makes them ideally suited to candidates for a university engineering degree.

In the present edition of the book the section on the design of aerofoil blading has been rewritten so that it may be directly applied to water turbines of the propeller type and to axial-flow air compressors.

British Council's Report

Although cultural activities of the British Council dominate its work in virtually every country of the world in which it is represented, the annual report for 1948-49 pays more than passing attention to its advocacy of British science and technology. As the British Council was voted ten per cent. less money for the year, its scale of activities and its staff were reduced, but a centre has been reopened in Switzerland, in response to many protests, particularly from the Swiss side; the foundation was laid for work in India and Pakistan; and there is to be considerable expansion in the Colonies.

In all oversea centres the British Council gathers a steady flow of inquiries upon scientific, medical, educational, artistic and other matters—information about research in the United Kingdom, and requests for standard publications. The Council provides only a limited number of specialist officers oversea, but the scope for them is wide. More tours abroad by lecturers from the United Kingdom were organized during 1949, and the main demand was for lectures on practical and scientific subjects, science and medicine accounting for 39 per cent. of the tours. Similarly, of the scholars accepted for assisted study in this country, medicine and education claimed 75 each, science 54, and engineering and sociology 25 each—considerably more than those for law, art, drama or music. Most of the 105 bursars drawn from 40 countries were in industrial occupations, and were placed with engineering and other firms. The same holds true of British books disseminated abroad by the Council: science, medicine, engineering and current English literature are the most popular subjects.

There have been important changes in the British Council's science organization. The engineering panel of advisers has been replaced by the secretaries of the three major engineering institutions (civil, mechanical and electrical), backed by their organizations, and the presidents of the three institutions have been appointed to serve on the Science Advisory Committee. This committee has been enlarged by an additional representative from the agriculture, medicine and general science panels, and from the Royal Society.

The science group of departments having been reorganized, there is now a new combined sciences department, which has taken over engineering and the technical side of the science services department, and it will serve as the technical department for all sciences other than agriculture and medicine.

Activities of the oversea science officers increased considerably during the year. The requests which they received "show that world reliance on British achievement in the sciences is not diminishing." Students in the sciences continued to hold a large proportion of the Council's scholarships. Advice on programmes for tours in this country were given to 55 visiting scientists, including 13 engineers. At the

end of 1949, 50 scholars in combined sciences were in Great Britain.

The Science Library compiled 134 bibliographies, which are now distributed to all Council libraries oversea, and requests for reprints and photocopies were numerous. Examples of further work of this kind include an exchange of publications between Chinese and British scientific institutions; and the sending to Polish and Turkish universities of instructional material for engineering students, involving over 300 items obtained from 27 British engineering firms.

One aspect of the year's work was growing recognition of the importance of the development of the Colonies, whose resources must be fully utilized if the standards of living of their peoples are to be improved, and the world's demands for raw materials met. Undoubtedly the process of development will be eased if a spirit of mutual trust and understanding can be fostered between the people of Britain and the peoples of the Colonies. This is the end to which the work of the Council in the Colonies is contributing.

During the year the Council's policy was clarified, and its relations with the Colonial Office defined. "It is fully accepted that the British Council is not a Government Department, or an official propaganda agency, or an agent of Colonial Government. Much importance attaches to its being left free to conduct its operations in its own way."

The Council has broken fresh ground in Hong Kong, Singapore and Malaya; and, in addition to extending activities in Nigeria, the Gold Coast and Kenya, it intends to send staff and increase services to Tanganyika, Uganda, Northern Rhodesia, Mauritius, Sarawak and North Borneo, Fiji, and the Windward and Leeward Isles.

The needs of the Colonies for local services are too great, and the financial resources too limited, to enable the British Council to service the Colonies with large-scale projects from the United Kingdom; the work of the centres depends to a large extent upon the cooperation of local residents of all races. The measure of success achieved "depends primarily on the extent to which the Council premises become a common meeting ground for different peoples and classes, and the focus for societies and organizations anxious to obtain insight into British ways of life."

Much stress is laid on the importance of teaching the English language in the countries of the Middle East; and in Latin America, as in the Middle East, the Council has had the delicate task of reducing expenditure, already low in relation to the importance of the work done, without arousing suspicion that the cause of reduction is indifference, rather than shortage of funds at the source. Further reductions would be disastrous in the Council's opinion, and could be made only by leaving more countries.

F.C.R.

Ybbs-Persenbeug: from p 38

The arguments introduced by Prof. Grzywienski for justifying the choice of the weir sill level at elevation 210.50^m to 211.50^m and the weir width of (5 × 30 = 150^m), are most interesting and summarise all the points which have to be considered in such cases, namely: Flood discharge; Backwater levels; Débris transportation, and Bed erosion.

The whole argument is backed by detailed calculations and comparative model tests. Floods from 7,000m^n/sec. to 10,000m^n/sec. were considered. Backwater curves were calculated by the method of difference (equation of Pressel) and, alternatively, by the equation of Bresse, and checked on a 1 : 200 scale model, at the "Staatliche Versuchsanstalt" (State Laboratory). This scale was, however, found to be too small and it was proposed to build a larger model at scale 1 : 100 or even larger. Special problems were investigated on models at the Polytechnical High School of Vienna.

The flow conditions through the piers of the weirs have been calculated with the equations of Weisbach and Rehbock. We would prefer the use of the equation of momentum (which gave good results for some model tests at the Hawksley Hydraulic Laboratory, Imperial College).

Débris transportation and the stability of the river bed were calculated from the empirical débris formula of Prof. Meyer Peter. Problems of bed erosion were solved by model tests. The weir toe is protected by a dentated sill, of the Rehbock type. Natural and artificial bed erosion downstream of the weir, in order to increase the available head, have also been considered.

Navigation on the Danube river is a major problem, which has to be borne in mind at every stage of the design of a scheme like Ybbs-Persenbeug. Provision is made in the project for two locks, one of 20 × 230 m^2 for upstream traffic, the other of 29.5 × 160 m^2 for downstream traffic. These locks would have to remain open in case of floods in order to avoid an excessively high backwater upstream of the weir. (When studying the navigation conditions through Geneva, a similar solution was proposed for passing the floods of the Rhône river). This proposal of Prof. Grzywienski is one of the main features of his project, reducing the total width of the weir to 5 × 30 = 150 m. which is then acceptable both for flood conditions and erosion. The discharge under flood conditions is thus 10,000/150 = 67 m^3/sec. per meter weir width, which had already been chosen by Prof. Grzywienski for the Drau-Scheme at Schwabeck.

From the financial point of view, the Ybbs-Persenbeug scheme was found to be about 40 per cent. too expensive. It would, however, be a paying proposition if part of the expenses were met by navigation and flood regulation, as should indeed be the case. The total costs are estimated at 190 million gold shillings for 150,000 kW installed capacity, against 90 million dollars for 160,000 kW at Kentucky dam.

(1). Dr. Ing. Anton Grzywienski "Das Donauwerk Ybbs-Persenbeug." Wien. Springer, 1949.

The International Commission on Large Dams will hold its next main meeting in New Delhi, India, in 1951. At the same time there will be an engineering exhibition, in which will be seen working models of river control schemes and various aspects of hydro-electric plant. The exhibition will also serve to interest the members of the World Power Conference who also meet in New Delhi, in that year.

Spanish Water Power Developments

By Mr. ROLT HAMMOND, A.M.I.C.E. Consideration is given to some recent projects that have features of special interest to civil engineers

Les installations hydro-électriques déjà en service en Espagne sont, à bien des égards, d'un intérêt très remarquable pour les ingénieurs civils, l'article ci-dessous examine certains des projets les plus récents. Une large part des progrès accomplis, déclare l'auteur, est due à la collaboration d'ingénieurs Britanniques et espagnols qui ont fait preuve d'une grande imagination et d'une habileté technique considérable dans les nombreux projets qu'ils ont conçus et menés à bien.

Los proyectos de fuerza hidráulica que ya se llevan completados en España tienen muchas características de interés poco vulgar para ingenieros industriales y en este artículo se discuten algunos de los proyectos más recientes. Una buena parte de los progresos realizados, dice el autor, son debidos a la obra combinada de ingenieros británicos y españoles que han demostrado grandes cualidades de imaginación y una muy gran habilidad técnica en los muchos proyectos que llevan diseñados y puestos a la práctica.

LACK of reliable statistics makes difficult an accurate estimate of the water power resources of Spain, but it has been computed that there are about six million horse power capable of being developed. In the works already carried out there have been many features of outstanding interest to civil engineers.

Spanish rivers are generally of a torrential character, and brief reference to a scheme in the Province of Granada with which the author was connected will serve to illustrate this point. Situated on the River Izbor, it comprises a diversion dam and intake works with about five miles of concrete lined aqueduct, the discharge from which flows into a concrete forebay and steel penstock, giving a head of about 300 metres and developing about 15,000 horse power with two vertical shaft Pelton wheels, each fitted with four jets and driving Metrovick generators. The River Izbor, from which the scheme derives its name, has an average gradient of 1 in 50 and its flow varies over wide limits according to the season. The only storage is that provided by the long aqueduct and the forebay, the dam being a diversion structure about 30 feet high; a trap has been built near the dam and this ensures that the water will be quite clear of sand when it reaches the power house. The latter is a reinforced concrete structure in which Hy-Rib reinforcement is incorporated in the walls. Power generated is employed for operating irrigation pumps in the Province of Almeria.

Although only a relatively small scheme, this is typical of many throughout Spain and especially in the southern provinces. In many parts of the country water power undertakings in the past have had difficulty in operating economically because of their inability to provide large dams for water regulation during periods of drought. The present tendency is for agricultural and electrical interests to combine together for the building of large storage dams, towards the cost of which the State contributes a share.

The most extensive development so far undertaken has been in the Pyrenees, but considerable schemes have also been carried out in the south, notably along the entire length of the Guadalquivir between Cordoba and Sevilla. Measures have also been taken to regulate the flow of water by the construction of large reservoirs. In 1926 a dam was built across the Jandula River which is carried to a height of 90 metres and stores 350 million cubic metres of water for irrigation and power generation purposes. By this and other works the *Compania Mengemor* has developed more than 100,000 horse power in Andalusia.

Another power development is that on the Gaduares River in the Province of Malaga, where the *Compania Sevillana de Electricidad* has built a concrete arch dam in the Montejaque Gorge for the development of 60,000 horse power. This dam is of unusual interest because of its size and the methods used in its construction. It has a maximum height of 273 feet from the lowest point in the foundation to the crest; there is a pressure tunnel driven through the rock for 7,200 feet, a penstock and a power house containing three generators operating under a maximum head of 900 feet. The spillway has been located 200 feet from the dam in the solid rock and has a capacity of 12,400 seconds feet. This dam is of the pure arch type, with variable radius in plan increasing from 72 feet at the base to 123 feet at the crest; the length along the centre line being 256 feet, with crest elevation 2,470 feet above sea level. Maximum width of the dam at elevation 2,247 is only 55 feet, which decreases to 10 feet at the top. Layout of the concrete chuting tower is shown in Fig. 1, the elevator bucket having a capacity of 60 cubic feet and dumping into the tower hopper of 84 cubic feet capacity; the hoist was driven by a 75 horse power electric motor. Concrete placing was carried out in four stages, and at the final tower height of 231 feet it was possible to bring

a part of the dam up to its final height by direct chuting. The last 1,200 cubic yards of concrete was placed by barrows. The structure was built in 4 feet layers corresponding to half the height of the steel forms employed. Quarry, crusher and mixing plant

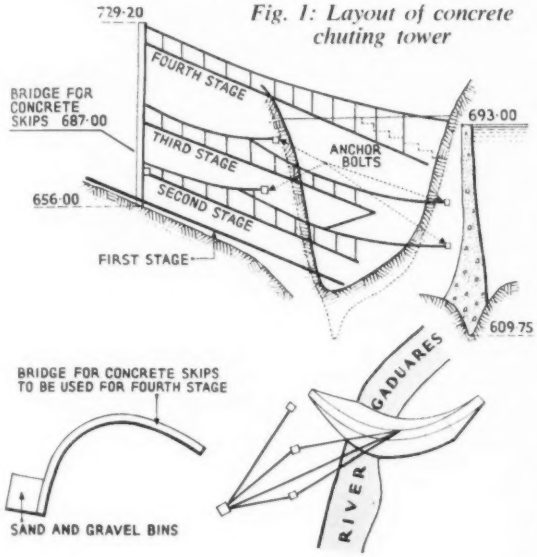


Fig. 1: Layout of concrete chuting tower

was designed as a unit to provide 270 cubic yards of concrete in eight hours, greatest quantity placed in one day was 450 cubic yards with the tower 60 feet high.

The Camarasa installation has many interesting features. Preliminary surveys indicated that there was a suitable site for a power house a few hundred feet above the confluence, where there is a deep canyon of limestone formation of very solid and massive character, with few bedding planes and joints, having a north-east dip below the dam and horizontal strata at and above the dam. Near the bottom of the canyon the limestone is very solid, free from open cracks and seams.

Borings carried out in the canyon indicated quite a satisfactory state of affairs but missed one important feature, a hole about 706,000 cubic feet in volume. However, it was proved that there was no need for pressure grouting. The left canyon wall rises to a height of more than 328 feet at an angle of 80 degrees and the right wall to the same height at an angle of 60 degrees; a convenient feature is that at the left cliff behind the site, where the slope became much greater and provided suitable facilities for a spillway to discharge at a safe distance below the dam. Rock excavated for this spillway afforded material for the construction of the dam.

A careful study was made of load characteristics in Barcelona in connexion with the Tremp and Seros installations; this proved that a plant between these two, designed to utilize normal daily river flow in a few hours, would have greater earning capacity and use a greater proportion of the annual flow of the river than a plant on the same general lines as those at Tremp or Seros. Thus, the plant at Tremp in 12 hours, working at 25,000 kW, discharges 77 million cubic feet of water which the Camarasa plant could make use of in six or seven hours.

It was a problem of considerable difficulty to carry out tests over a sufficient length of time to provide the necessary data for the design of the Camarasa plant, which is shown in Fig. 2. The basic figures were derived from the average annual flow at Pobla of from 45,000 to 49,000 million cubic feet, giving a total average head of 228 feet above the level of the tail race with an effective head of 216 feet at the turbines. Corresponding output is 110 million kWh, giving an all round efficiency of 72 per cent., a result confirmed by individual plant and machine trials.

Considerable interest attaches to the Tranco de Beas scheme, one of the largest developments in Spain (see Fig. 3), where a curved masonry dam 90 metres high impounds 500 million cubic metres of water in the reservoir. The power station is located completely underground, as shown in Fig. 4, operating under a maximum head of 109.7 metres and a minimum head of 58 metres, maximum flow is 50 cubic metres a second. The present generating plant comprises two units using 20 cubic metres of water

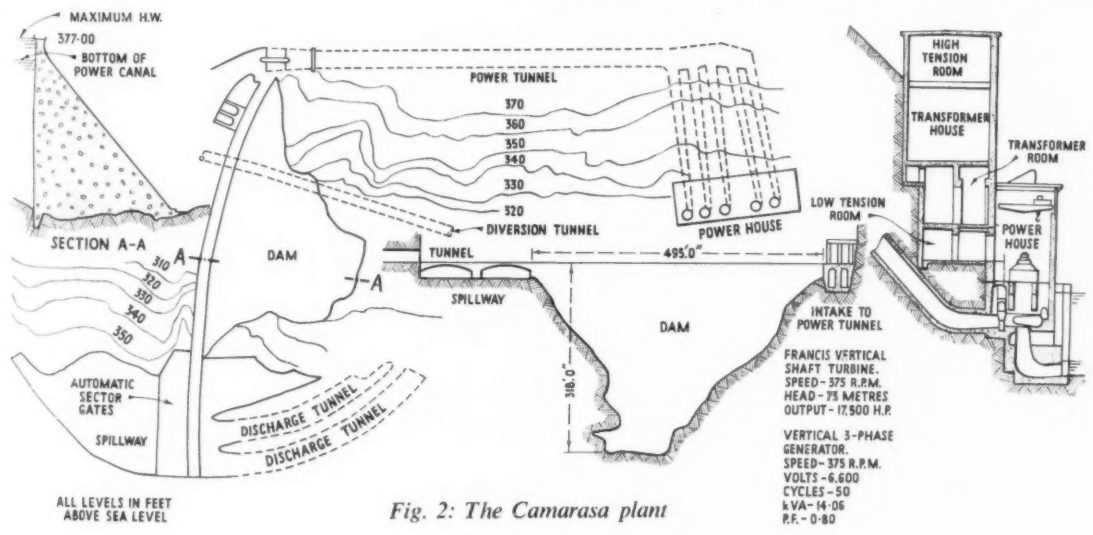
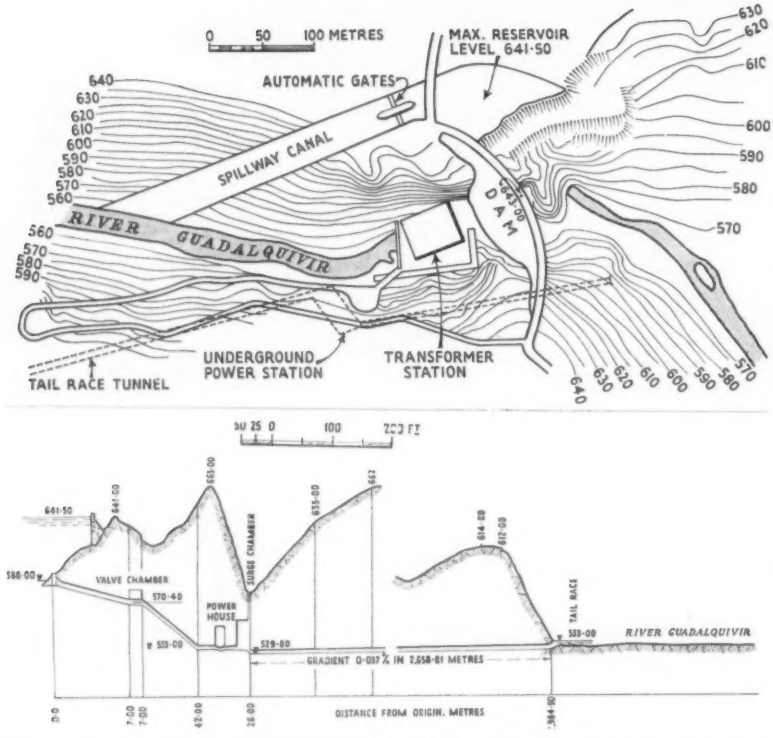


Fig. 2: The Camarasa plant



operating at 13.8/138 kV at 25,000 kVA rating and one transformer of 13.8/66 kV at a rating of 20,000 kVA. Current at 138 kV will be fed into the national grid.

The Salto de Zorita scheme is another project of absorbing interest; Fig. 6 shows a cross section of the dam, which supplies water to the power house (Fig. 7) by a canal providing for a maximum discharge of 80 cubic metres a second at a velocity of 2.1 metres a second. Diameter of the penstocks supplying the turbines with water is 3.8 metres and flow can be shut off completely by square sluice gates (3.5 metres). The tail race is a rectangular channel 30 metres long lined throughout with concrete; excavation for power house and tail race involved some 40,000 cubic metres. The power house structure is in mass concrete reinforced only around the turbine scrolls, the super-

a second and one unit consuming 10 cubic metres a second, with a total output of 54,750 horse power under a head of 100 metres. Water flows to the power house through a pressure tunnel 283 metres long and 3.4 metres diameter; after giving up its energy to the turbines it flows through the tail race tunnel which is 2,638.8 metres long and 4 metres in diameter. The alternators supply current at 13.8 kV which is stepped up to 138 kV for transmission. Average annual production of electrical power amounts to 52,000,000 kWh.

The underground power house is seen in section in Fig. 5. The strata in which it is built comprises lower and middle Jurassic limestone of a strong yet permeable nature. Flow of water is controlled from an underground valve chamber and no sluice gate has been erected at the intake; the reason for this apparent omission is that the intake could only be constructed during short periods in the autumn season when the reservoir is low and when the intake is uncovered. Access to the underground valve chamber is through a horizontal tunnel 40 metres long, downstream of the dam and independent of water level in the reservoir. The power house is excavated in the solid rock and has a concrete arch 40 metres long with a span of 13.9 metres, access being through a vertical shaft 8.6 metres by 7.5 metres, with a passenger lift and another for handling machinery and materials, the shaft also acting as a duct for bus bars and ventilating pipes.

A surge chamber is arranged at the turbine outlet, and the tail race tunnel is 4 metres in diameter, designed to operate at full bore and under slight head. The transformer station is downstream of the dam and is equipped with two step-up transformers

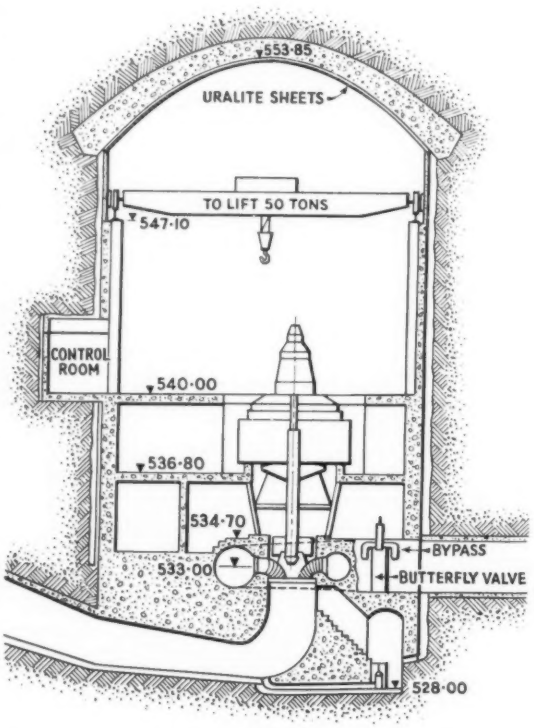


Fig. 3 (top left): Tranco de Beas development
Fig. 4 (left): Cross section of Tranco de Beas
Fig. 5 (above): Tranco de Beas power house

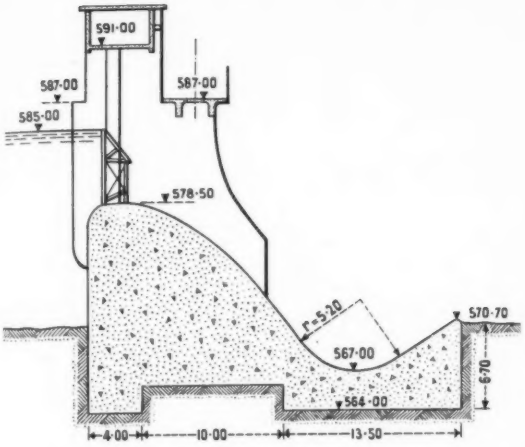


Fig. 6: Cross section of Salto de Zorita dam

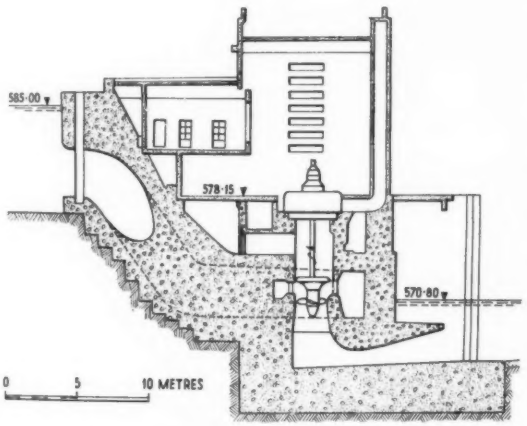


Fig. 7: Salto de Zorita power house

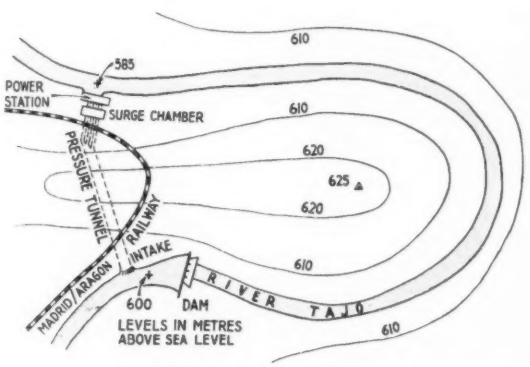


Fig. 8: Layout of Zorita de los Canes scheme

structure being in reinforced concrete. These works were begun in November, 1943, and finished in June, 1947, when the first generating unit came into operation

Layout of the Zorita de los Canes scheme is shown in Fig. 8 and this is located on a meandering river. The dam is 65 metres long and is equipped with three

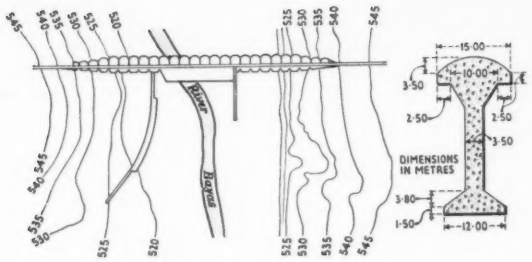


Fig. 9: Plan and section of Ullivari dam

sluice gates each 15 metres wide and 5.5 metres high, separated by piers of mass concrete 3 metres wide. The sluice gates have been designed to pass a normal flood of 1,600 cubic metres a second and an abnormal flood of 2,100 cubic metres a second, level of the water in the latter case being one metre above normal. Each sluice gate provides for the automatic discharge of flood water up to 10 cubic metres a second and the passage of floating debris.

The foundations were carried out without diverting the river. The pressure tunnel is 800 metres long of circular section 5.5 metres in diameter, designed to take a maximum discharge of 80 cubic metres a second at a velocity of 3.16 cubic metres a second; the tunnel lining has a maximum thickness of 50 centimetres, with internal gunite finish 3 cms. thick. Gradient is 1 in 100, head of water on the centre line varying between 5.75 metres at the inlet and 13.75 metres at the outlet. At the outlet of the pressure tunnel there are three branch tunnels, of circular section and 3.8 metres in diameter, the surge chamber being connected with these three branch tunnels. Movement of the water when the turbine valves are opened or shut is very complicated, and was studied by means of a scale model at the laboratory of the School of Highways, using the method of similarity proposed by Stucky, which enables accurate

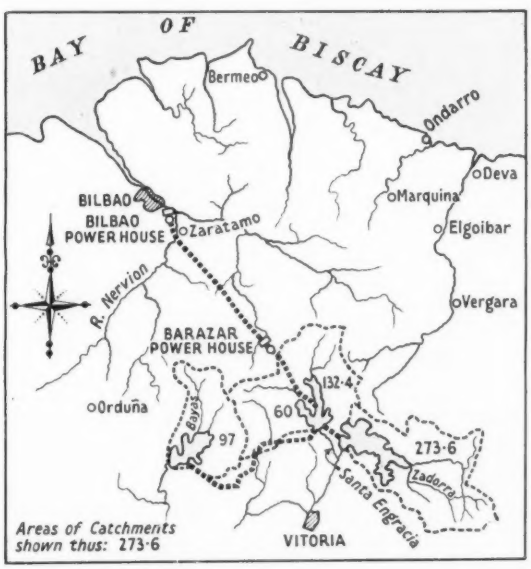


Fig. 10: Map showing schemes near Bilbao

reproduction to be made of loss of head, flow of water and oscillation phenomena.

These works were begun in 1944, and the first generating group came into action in 1947; since that date the power station has made an important contribution to power supply in central Spain. It is hoped that the normal six monthly output will be about 40 million kW.

In Fig. 10 we have a sketch map and some details of water power developments in the Bilbao region, where three projects have been undertaken with gross heads of 295, 105 and 100 metres respectively, the aqueducts varying in capacity from 9 to 18 cubic metres a second. Respective outputs are 53,000, 19,000 and 9,000 horse power, representing a total output capacity of 81,000 horse power. Here in the Basque country is one of the most important consuming centres of electrical power in Spain. Capacity of the three reservoirs of Bayas, Santa Engracia and Zadorra has been fixed after a complete analysis of all the factors involved, and the total volume of water provided amounts to 295 cubic hectometres; the top water levels of these reservoirs lie at 546 and 610 metres above sea level respectively.

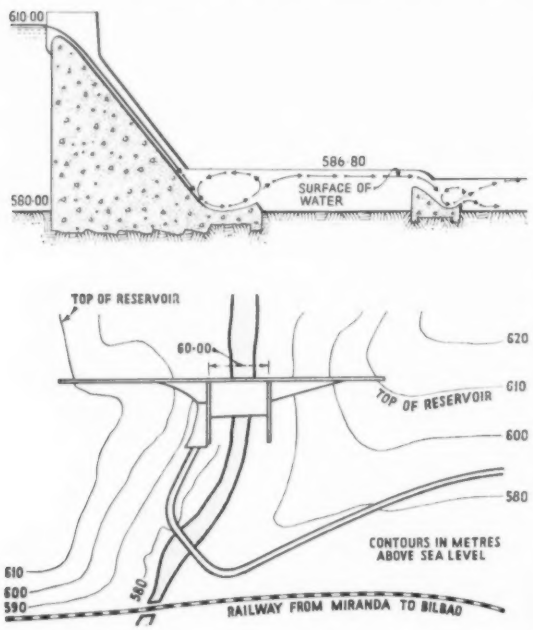


Fig. 11: Cross section and plan of Bayas dam

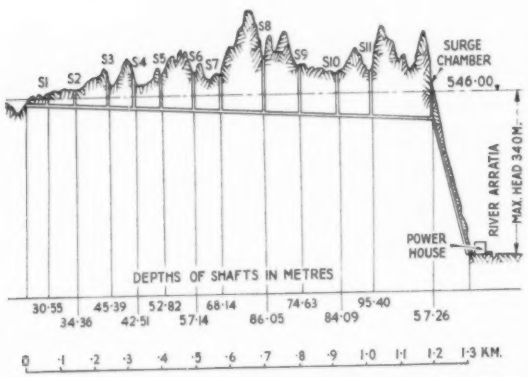


Fig. 12: Longitudinal section of Barazar Aqueduct

The Zadorra and Santa Engracia reservoirs are connected by pressure tunnel of circular cross section, 3,551 metres long and 2.5 metres in diameter; each impounding dam is slightly more than 450 metres long and has heights of 36 and 31 metres respectively, constructed on the counterfort principle, as shown in the sketch of the Ullivari dam (Fig. 9). The Bayas dam (Fig. 11) is a straight gravity type of structure, 36 metres high and having a total volume of 73,000 cubic metres of concrete. The flow that can be drawn from the Zadorra, Santa Engracia and Bayas dams, without lowering the top water level, is in each case 570, 406 and 350 cubic metres a second.

In the Barazar power station (see Fig. 12) there are four Francis type turbines operating on heads ranging from 266 to 340 metres, with a maximum flow of 13.33 cubic metres a second, giving outputs of 47,000 and 56,000 horse power in each case. The alternators are direct coupled to the turbines and have a capacity of 42,000 kVA, the step-up transformers providing a voltage of 132 kV for the transmission line.

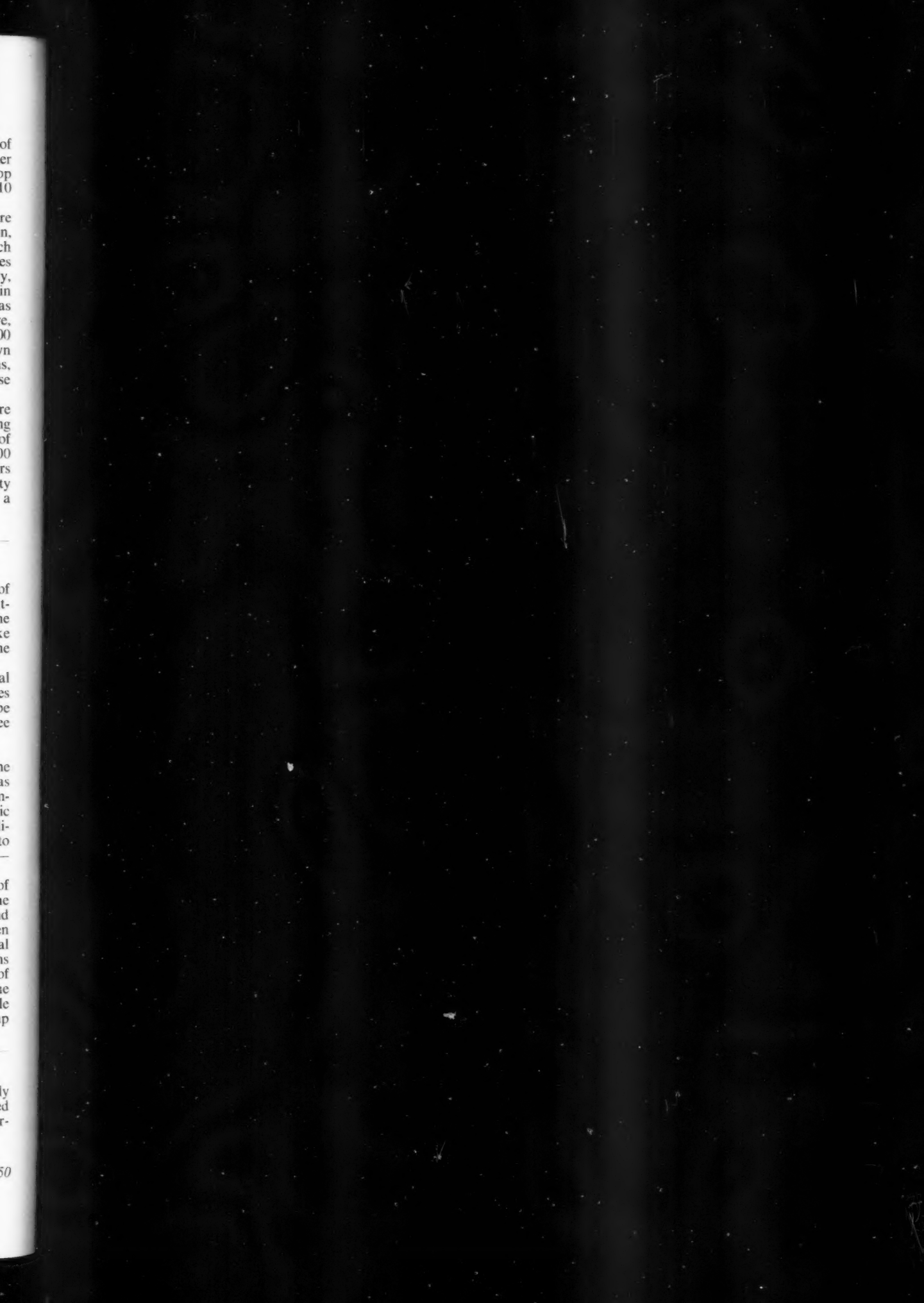
CONTRACTORS' NOTES

The General Electric Company.—On account of illness, Mr. C. F. A. Dobson has resigned his appointment as manager of the conduit department of the General Electric Company and on his return will take up a senior position in the sales organisation of the company.

Mr. W. Lewis Smith, manager of Pirelli-General wire and cable and wiring sundries departments, takes over the control of conduit department and will be responsible for the general management of these three departments.

Pirelli-General Cable Works, Southampton.—One of the latest five inch lead extrusion machines has just shipped to the U.S.A. and will shortly be installed in the Baltimore plant of the Western Electric Company, where it will join others made by Pirelli-General. Continuous extrusion machines supplied to North America by this company now total eight—three have gone to Canada and five to the U.S.A.

Another recent U.S.A. installation forms part of an expansion and improvement programme at the Marion Indiana factory of the Anaconda Wire and Cable Company, where a three inch machine has been erected under the supervision of a Pirelli-General engineer. Delivery was ahead of schedule. Test runs have been completed satisfactorily and as a result of continuous operation, now made possible by the extrusion machine, the output of lead sheathed cable from the Marion Mill is expected to increase by up to 25 per cent.

PUBLISHER'S NOTE

It is regretted that the second colour invariably associated with the announcements of British Insulated Callender's Cables Ltd. was omitted in the November-December issue of *WATER POWER*.